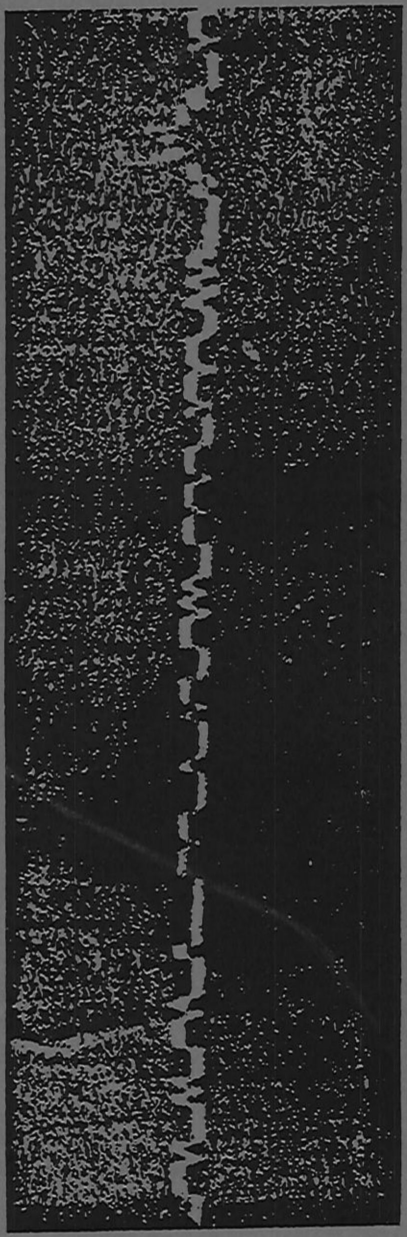


The First Published Photographic Record of a Transatlantic Message.

This message was transmitted from Glace Bay, N.S., and received at the Marconi Station, Clifden, Ireland. The record was made by an Einthoven Galvanometer, actuated by the Detector Current.

Frontispiece.

A HANDBOOK OF
WIRELESS TELEGRAPHY
Its Theory and Practice

FOR THE USE OF ELECTRICAL ENGINEERS, STUDENTS, AND OPERATORS

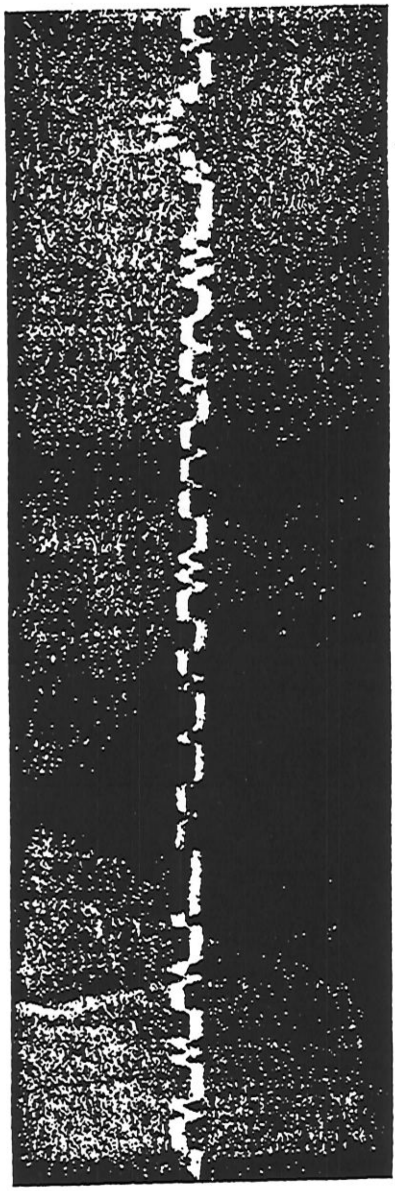
BY

JAMES ERSKINE-MURRAY, D.Sc.

FELLOW OF THE ROYAL SOCIETY OF EDINBURGH
MEMBER OF THE INSTITUTION OF ELECTRICAL ENGINEERS
FELLOW OF THE PHYSICAL SOCIETY OF LONDON

Fifth Edition Revised and Enlarged

LONDON
CROSBY LOCKWOOD AND SON
7 STATIONERS' HALL COURT, LUDGATE HILL, E.C.
AND 5 BROADWAY, WESTMINSTER, S.W.
1914



The First Published Photographic Record of a Transatlantic Message.

This message was transmitted from Glace Bay, N.S., and received at the Marconi Station, Clifden, Ireland. The record was made by an Einthoven Galvanometer, actuated by the Detector Current.

Frontispiece.

A HANDBOOK OF

WIRELESS TELEGRAPHY

Its Theory and Practice

FOR THE USE OF ELECTRICAL ENGINEERS,
STUDENTS, AND OPERATORS

BY

JAMES ERSKINE-MURRAY, D.Sc.

FELLOW OF THE ROYAL SOCIETY OF EDINBURGH
MEMBER OF THE INSTITUTION OF ELECTRICAL ENGINEERS
FELLOW OF THE PHYSICAL SOCIETY OF LONDON

Fifth Edition Revised and Enlarged

LONDON
CROSBY LOCKWOOD AND SON
7 STATIONERS' HALL COURT, LUDGATE HILL, E.C.
AND 5 BROADWAY, WESTMINSTER, S.W.
1914

Printed at The Darien Press, *Edinburgh*

This Book is dedicated

TO THE MEMORY OF

THE LATE

LORD KELVIN, O.M., G.C.V.O.

TO WHOSE INSPIRING TEACHING

AND SYMPATHETIC INTEREST

IT OWES WHATEVER

SCIENTIFIC MERIT

IT MAY

POSSESS.

FIRST EDITION, 1907
SECOND EDITION, 1909
THIRD EDITION, 1911
FOURTH EDITION, 1913
FIFTH EDITION, 1914

PREFACE TO THE FIFTH EDITION.

THE present edition differs from the last in various details, the most considerable additions being in regard to the uniform alternating current and shock excitation systems. Recent measurements of transmitted power have also been added.

I venture to take this opportunity of pointing out that although this volume has to some extent the character of a text-book, it has never been a mere *rechauffée* of previously published material, but has in every edition contained some work of an original nature. If, for instance, the conception of modern wireless telegraphy given in the first edition had been more quickly recognised by subsequent theoretical writers as fundamental, much time and labour might have been saved in the development of the subject. The same is true of the proof of the importance of the resistance of the Earth's surface given in the chapter on Transmission, and of the discussion of the existence and function of the upper conductive layer of the atmosphere.

Again, the theory of telegraphic efficiency, and the experimental method for the determination of the radiation efficiency and other constants of a wireless station, first published in the fourth edition, were practically entirely new at the time of publication.

J. ERSKINE-MURRAY.

LONDON, *December* 1913.

PREFACE TO THE FIRST EDITION.

THIS "Handbook of Wireless Telegraphy" (it need hardly be said) is not encyclopædic; nor, on the other hand, does it pretend to be a simple exposition of its subject for the benefit of the uninitiated. Rather it is intended for the use of those who, for reasons of business or pleasure, have already made themselves acquainted with at least some of the truths of the theory and practice of wireless telegraphy, and to whom, therefore, the ordinary technical terms will convey something more concrete than a mere definition in words.

Few, if any, quotations are made in the volume which do not bear directly on wireless telegraphy, and those which are inserted are given fully. The reader should, therefore, have sufficient material on which to form his own estimate of the practical bearing of some of the more important researches of earlier workers in this subject.

The thanks of the Author are due to the Companies and Firms who have kindly supplied him with details of their operations and with blocks illustrative of their systems, thus enabling him to give, also, authoritative descriptions of the latest developments. Statements of achievements have been backed, as far as possible, by reports of official experts, but failing this, results have, as a rule, been given on the authority of the inventors or of the assignees of their patents.

In Chapter XVII. will be found the Author's views on the subject of the mechanism of Transmission. These are based on the latest researches; and although as yet the theory is far from complete, it will be seen that some advance has been made through the consideration of actual outdoor circumstances, in addition to results of experimental measurements.

The Tables in Chapter XXI. form a unique feature of the volume, and should render it useful to those engaged in the practice of wireless telegraphy. Most of them have been calculated by the Author and appear in print for the first time. They deal with such data as the inductance of helices, capacity of condensers of various forms and sizes, resistance of various conductors to high frequency currents, and similar numerical quantities required in the design of radio-telegraphic apparatus. As the calculation of these Tables has involved a large amount of arithmetical work, it is possible that (in spite of precautions) some errors may have crept in, and the Author would be grateful if any reader who may discover any error will kindly communicate with him through the Publishers.

Chapter XX. is an almost literal translation of a paper "On the Calculation of a Syntonic Wireless Telegraph Station," by Signor Alfredo Montel, which was published at Rome in June 1906. It gives concisely, with numerical examples, the calculations necessary for the design of a modern wireless telegraph station. The Author's grateful thanks are due to Signor Montel, and to the proprietors of *L'Elletricista* for their kind permission to reproduce here in English dress a translation of this most useful and important paper.

From what has been said, it will be seen that the Author has tried to confine himself strictly to modern open circuit wireless telegraphy, and has omitted methods of communication which do not come under that description. In regard to mathematical theory, he has avoided, as far as possible, the discussion of any problem which remains to be dealt with more satisfactorily by experiment. In regard to the relative merits of close and loose coupling, and many other questions arising in practical work, it must be remembered that, with the instruments now at the command of wireless telegraph engineers, it is possible in the course of a brief experiment to obtain comparative results which are as satisfactory as a mathematical demonstration could be.

It should be mentioned that the Author has taken it upon himself to introduce one or two new terms—such as "jig," "equifrequent," and "revibration." The first is short for "an alternating electric current of the high frequency usually adopted in wireless telegraphy"; while the others are almost self-explanatory, "revibration" describing in general the action of which resonance is a particular example.

In addition to acknowledgments already made, the Author must express his grateful thanks to the authors and publishers who have assisted him by supplying information, or by granting permission for the use of extracts or illustrations from published matter. In particular he has to thank the proprietors of the *Electrician*, without whose generous aid it would have been impossible for him to have included authorised or full descriptions of many recent discoveries; as well as the Royal Societies of London and Edinburgh, the Royal Physical Society, the Institution of Electrical Engineers, and the proprietors of the *Philosophical Magazine*, the *Electrical World and Engineer* (*New York*), and the *Electrical Review*. He is likewise indebted to Messrs Longmans and Professor Fleming for blocks illustrative of the Marconi system; to Messrs Macmillan and his friend Professor Gibson for an extract from the latter's treatise on "Graphs"; to Mr Commerford Martin for extracts from his "Inventions of Nikola Tesla"; and to Dr Barth, of Leipsic, for blocks taken from Hertz's "Electric Waves."

Finally, he must express his thanks to his friend Professor Magnus Maclean for kindly checking the Tables of Chapter XXI., and to Professor Andrew Jamieson for many useful hints during the progress of the work.

LONDON, *February* 1907.

CONTENTS.

CHAPTER I.

PAGE
ADAPTATIONS OF THE ELECTRIC CURRENT TO TELEGRAPHY 1

CHAPTER II.

EARLIER ATTEMPTS AT WIRELESS TELEGRAPHY - - 33

CHAPTER III.

APPARATUS USED IN THE PRODUCTION OF HIGH FREQUENCY CURRENTS - - - - 48

CHAPTER IV.

DETECTION OF SHORT-LIVED CURRENTS OF HIGH FREQUENCY BY MEANS OF IMPERFECT ELECTRICAL CONTACTS - - - - - - - 73

CHAPTER V.

DETECTION OF OSCILLATORY CURRENTS OF HIGH FREQUENCY BY THEIR EFFECTS ON MAGNETISED IRON - - - - - - - 91

CHAPTER VI.

PAGE
THERMOMETRIC DETECTORS OF OSCILLATORY CURRENTS OF HIGH FREQUENCY RECTIFIERS - - - 113

CHAPTER VII.

ELECTROLYTIC AND OTHER DETECTORS - - - 131

CHAPTER VIII.

THE MARCONI AND LODGE-MUIRHEAD SYSTEMS - - 137

CHAPTER IX.

THE FESSENDEN SYSTEM - - - - - 175

CHAPTER X.

THE HOZIER-BROWN SYSTEM - - - - 191

CHAPTER XI.

WIRELESS TELEGRAPHY IN ALASKA - - - 197

CHAPTER XII.

UNIFORM ALTERNATE CURRENT SYSTEMS—THE POULSEN SYSTEM—THE GOLDSCHMIDT SYSTEM - - 201

CHAPTER XIII.

PAGE
THE LEPEL, THE TELEFUNKEN, AND OTHER SHOCK-EXCITATION SYSTEMS - - - - 211

CHAPTER XIV.

ANTENNAS - - - - - 221

CHAPTER XV.

SOME POINTS IN THE THEORY OF JIGS AND JIGGERS - 238

CHAPTER XVI.

THE THEORY OF TRANSMISSION - - - - 263

CHAPTER XVII.

WORLD-WAVE TELEGRAPHY - - - - 312

CHAPTER XVIII.

ADJUSTMENTS, ELECTRICAL MEASUREMENTS, AND FAULT TESTING - - - - - - 331

CHAPTER XIX.

THE TELEGRAPHIC EFFICIENCY OF A WIRELESS SYSTEM 361

CHAPTER XX.

PAGE
ON THE CALCULATION OF A SYNTONIC WIRELESS TELEGRAPH STATION - - - - - - 378

CHAPTER XXI.

TABLES AND NOTES - - - - - - 394

Morse Codes:—European or Continental Code; American Code. Table I.—Dielectric Strengths of Various Insulators. Table II.—Specific Inductive Capacities or Inductivities. Definitions and Formulæ. Table III.—Conductivities of Metals. Table IV.—Capacity of Parallel Plate Condensers. Table V.—Capacity of a Cylindrical Condenser. Table VI.—Capacity of Vertical Wires of Various Diameters and Lengths in Millionths of a Microfarad. Table VII.—Inductance of Helix per cm. of Length. Formulæ for inductances of Various Forms. Table VIII.—Resistance of Straight Copper Wires to Constant and to High Frequency Currents. Table IX.—Ratio of H.F. Resistance R″ with Damping, to R′, the Resistance given in Table VIII. for Uniform H.F. Currents. Notes on Spark Resistance. Table X.—Spark Lengths in Air, with Spark Balls of Various Sizes. Table XI.—Small Sparking Distances in Air in Millionths of a Millimetre. Determination of Damping. Damping of Various Forms of Aerial. Notes on Petrol Engines, Dynamos, and Accumulators. Notes on Ropes. Hickman's Slide Rule. Time Signals. Sensibility of Telephones. Dielectric Losses in Condenser.

APPENDICES.

1. RADIOTELEGRAPHIC CONVENTION SERVICE INSTRUCTIONS, INCLUDING 1912 REGULATIONS - - 413

2. IMPERIAL WIRELESS STATIONS, MARCONI COMPANY'S ORIGINAL SPECIFICATION FOR - - - - 429

INDEX - - - - - - - - 435

SELECTED LIST OF ILLUSTRATIONS.

PAGE
Record of Transatlantic Messages - *Facing Title-page.*
Wire Telegraph Earth Return - - - - - - 2
Closed Circuit Wireless Telegraph - - - - - 2
Principal Conductors in Modern Wireless Telegraphs - - 4
Distribution of Electric Force before Spark occurs - - 5
Lodge's Syntonic Leyden Jar Circuits - - - - - 10
Hertzian Oscillator - - - - - - - 10
Hertz's Diagrams of Electric Radiation - - - - 18
Popoff's Receiver - - - - - - - 22
Tesla's High Frequency Transformer - - - - - 25
Superposition of Impulses causing Revibration - - 29
Dolbear's Wireless Telegraph - - - - - - 34
Tesla's Proposed Wireless Telegraph - - - - - 35
Marconi's Earthed System (early form) - - - - 38
Jigger, Two Methods of Connection to the Coherer Circuit - 41
Lodge's Syntonic System, Principal Conductors - - 44
Slaby Receiving Station, Principal Conductors - - 45
Microphone as Detector in Conjunction with Telephone - 46
Tesla's High Frequency Alternator - - - - - 49
Goldschmidt's Alternator - - - - - - - 51
Elihu Thomson Generator - - - - - - 54
Braun's Oscillograph - - - - - - - 61
Barkhausen's Methods for Characteristic Curves - - 64
Marconi's Form of Coherer - - - - - - 75
Eccles's Diagram of Coherer Tests - - - - - 82
Marconi's Magnetic Detector - - - - - - 93
Fessenden's Electro-magnetic Receiver - - - - 95
Ewing and Walter Magnetic Detector - - - - - 99
Eccles's Diagrams on Magnetic Detectors - - - - 106
Fessenden's Barreter - - - - - - - 114
Tissot's Bolometer - - - - - - - 116
Snow Harris Thermo-galvanometer - - - - - 119
Duddell's Thermo-ammeter - - - - - - 120
Sensitiveness Curves of Detectors - - - - - 127

PAGE
Electrolytic Detector - - - - - - - 132
Fleming's Vacuum Valve - - - - - - 134
Modern Marconi Station - - - - - - 138
Gray Sending Key for Alternating Circuit - - - 140
Marconi Transatlantic Station - - - - - 141
Marconi Tuner - - - - - - - - 144
Marconi Uniform H.F. Generator - - - - - 147
Resonance Curves of Marconi Transatlantic Station - - 152
Lodge-Muirhead Coherer - - - - - - 159
Lodge-Muirhead Interrupter - - - - - - 160
Lodge-Muirhead Oscillator - - - - - - 163
Diagram of Lodge-Muirhead Apparatus - - - 165
Map showing Stations in Andaman Islands and Burma - 169
Fessenden Station at Machrihanish, Aerial Conductor - 176
Fessenden's Machrihanish Station—Wave-chute - - 179
Fessenden's Interference Preventer - - - - 182
Variations in Intensity of Transatlantic Messages - - 189
Hozier-Brown Receiver - - - - - - - 192
Goldschmidt 150 K.W. H.F. Alternator - *facing page* 201
Poulsen Station - - - - - - - - 202
Pedersen High-Speed Transmitter - - - - 205
Lepel Station - - - - - - - - 213
Telefunken Station - - - - - - - 216
Lodge-Chambers' System - - - - - - 220B
Marconi's Diagrams of Directive Transmission - - 230
Bellini and Tosi, Radiogoniometer - - - - 232
Zenneck's Diagrams on Directive Transmission - - 235
Receiving Transformers - - - - - - - 246
Resonance Curves - - - 152, 253, 254, 256, 356, 358
Diagram of the Earth and Atmosphere - - - 264
Captain Jackson's Experiments on Screening - - - 271
Duddell and Taylor's Sketch Chart, Howth to Holyhead - 275
Curves showing Current Variations with Distance - - 276
Propagation of Jigs along Earth's Surface - - - 279
Distribution of Earth's Surface Resistance near Receiver - 287
Zenneck and Hack's Diagrams on Transmission - 289-294
Tesla's Transmitting Station on Long Island - - - 318
Fleming's Cymometer - - - - - - - 350
Dönitz Wavemeter - - - - - - - 352
Determination of Damping - - - - - - 357
Diagrammatic Tables - - - - - - 394-411
Map of Coast Stations in British Isles - - - - 412

A HANDBOOK OF WIRELESS TELEGRAPHY

CHAPTER I.

ADAPTATIONS OF THE ELECTRIC CURRENT TO TELEGRAPHY.

PROGRESS in the branch of electric telegraphy usually called "wireless" has been so very rapid that many of the technical terms used have not yet had definite meanings attached to them. To begin with, the term "wireless" itself is used vaguely to cover many systems of totally different kinds which have in common only the fact that no insulated conductor joins the sending and receiving stations. The use of the word is no doubt correct, but it leaves undefined the type of apparatus and method of transmission.

Some writers attempt to distinguish the more modern methods as "electric wave telegraphy," "space telegraphy," "Hertzian telegraphy," "spark telegraphy," and so on; but few if any of these designations really go to the root of the matter, and many of them might equally well be applied to systems totally unlike those which they are meant to describe; even "radio-telegraphy" is ambiguous.

Let us consider the course of the electric current in various telegraphic systems.

In ordinary wire telegraphy the current goes by the whole Earth and returns by the wire. Telegraphists usually put it the other way, but it is a matter of indifference. The circuit is a closed conducting loop, and, barring unintended leakage, the whole current sent out passes through the receiver.

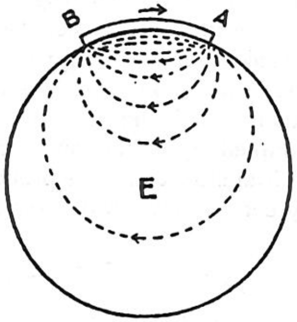


FIG. 1.—WIRE TELEGRAPH.
E, the Earth; *A B*, Insulated Wire connected to Earth through Sending and Receiving Instruments at *A* and *B*. Arrowheads show direction of current.

In the Morse, Lindsay, and Willoughby-Smith systems a current is made to flow between two plates buried in the earth or sea, and the receiver current is picked up by other earth-plates placed on the lines of flow of the current. The conducting circuit is still a completely closed one. In fact, it exactly resembles a shunted galvanometer. The earth is the shunt, hence only a small proportion of the transmitted current flows through the receiver.

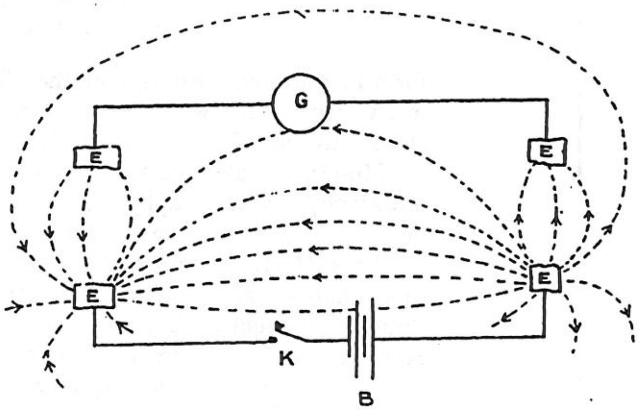


FIG. 2.—GENERAL DIAGRAM OF CLOSED CIRCUIT WIRELESS TELEGRAPH (Morse, Lindsay, Willoughby-Smith).
E, Earth-Plates; *K*, Transmitting Key; *B*, Source of Current; *G*, Receiving Galvanometer. Arrowheads show direction of current in earth or sea.

One of Sir Oliver Lodge's systems, not that in most general use, depends on varying magnetic induction through two closed conducting circuits, one at the sending and the other at the receiving station. No current of electricity passes from one to the other, but only the magnetic force.

Between these extremes stand the systems which have been most successful. In all of them a conduction current, not continuous, but alternating, passes through the upper layers of the earth's surface from the sending to the receiving station. As, however, there is no return wire the current spreads, as a rule, equally in all directions round the transmitter.

Reduced to its simplest terms the modern wireless telegraph is a large conducting sphere (the earth) with two conducting excrescences on it or near its surface (the aerial conductors). In one of these a sudden oscillatory movement of electricity is started, which spreads over the surface, causing to-and-fro currents in the other wire as it passes.

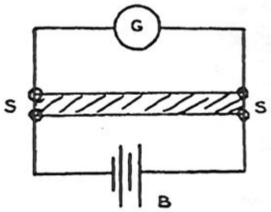


FIG. 3.—SHUNTED GALVANOMETER (Compare with Fig. 2.)
B, Source of Current; *S S*, Thick Conductor used as Shunt; *G*, Galvanometer.

In several systems no conducting connection is made between the aerials and the earth. In such cases the current becomes in places a dielectric displacement. It is, however, a true current in the general sense, and the configuration of its lines of flow is similar to that in the entirely conducting systems, except that there may in the Lodge-Muirhead system be in addition a set of closed lines of force or direct radiation propagated outwards above the earth.

So far we have considered mainly the conduction current. There is always associated with it a steady or

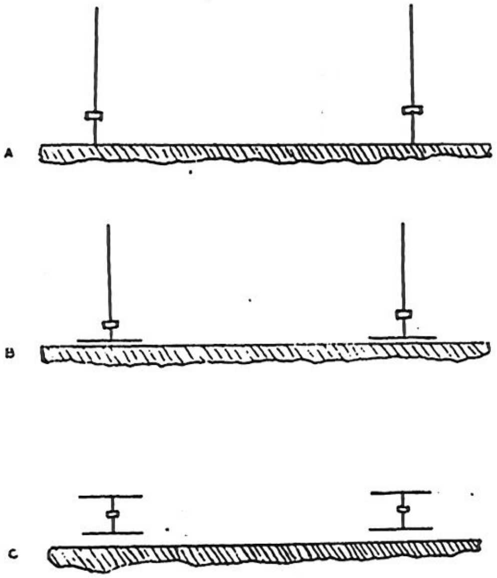


FIG. 4.—PRINCIPAL CONDUCTORS IN MODERN WIRELESS TELEGRAPHS.

A, Aerial Wires connected conductively to Earth through Transmitting and Receiving Instruments; *B*, Aerial Wires connected inductively to Earth by means of Wire Netting spread on ground; *C*, Lodge-Muirhead system.

varying displacement in the dielectric or insulator surrounding it—in our case in the atmosphere. In wireless telegraphy this displacement is rapidly alternating and in itself constitutes a dielectric current, or perhaps we should rather say, currents, since the lines of force do not, except in the case of stations within short distances of one another, bridge directly from one aerial to the other. Of course, if the first process of charging the sending aerial is comparatively slow, taking, for instance, as much as a thousandth of a second, the lines of force will have time to spread a great distance, and the electrification on the aerials and earth's surface will have attained a practically static condition before any further change occurs. The lines of force move outward at about 186,000 miles per second, so that in one-thousandth of a second the far ends of the outermost ones will, where they touch the earth, have reached a distance of 186 miles, the near ends still remaining on the sending aerial. Thus we see why it is possible to obtain a signal at many miles' distance when the primary circuit of a coil is broken, even though no spark occurs in the secondary circuit and no oscillations take place.

In systems in which the aerial does not contain a spark-gap, but is coupled by induction to a separate oscillating circuit, this initial slow charge is probably quite negligible; it is certainly evanescent. Most systems now in use conform to these conditions, and therefore do not commence every wave train with an odd wave of great length, but start with one of the same length as those which follow it.

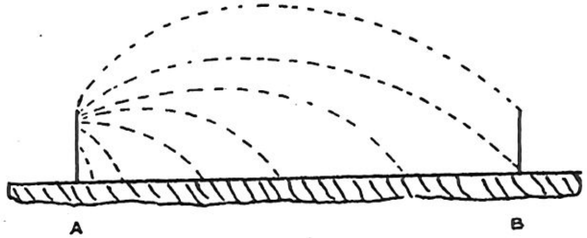


FIG. 5.—DISTRIBUTION OF USEFUL LINES OF ELECTRIC FORCE BEFORE SPARK OCCURS WHEN DISTANCE SMALL.

A, Transmitting Aerial; *B*, Receiving Aerial.

Modern wireless telegraphy is, in general, open circuit telegraphy, *i.e.*, telegraphy from one part of a conductor to another without the use of a return wire.

True Hertzian telegraphy, with small radiators placed more than a wave length above the ground, uses no continuous conductor between the stations. *Short-wave* Hertzian telegraphy has never been successful at distances beyond a mile or two, and apparently cannot compete with systems which utilise the earth as conductor to guide the current round corners, or with long-wave systems in which diffraction performs the same function. As a matter of fact, all the systems now in use have either direct conducting connections with the earth or have the lower end of the vertical aerial so near the ground that the condenser formed by the two is nearly as capable of carrying the oscillating current as a conductor would be.

I shall leave questions of priority of invention to historians and lawyers, and content myself with describing only the experiments which appear to have contributed most directly to the development of the new means of communication. *It should therefore be understood that where dates are mentioned they apply only to the matter in hand and do not imply the commencement of the work of any particular experimenter or even his first publication on the subject.*

Closed Circuit Wireless Telegraphy.—The earlier systems* of electric telegraphy without connecting wires such as those of Morse and Lindsay depended on the detection of minute differences of potential between two earth-plates sunk at some distance apart on a line flow of the current between the two earth-plates of the transmitter. These lines of flow resemble, in form, the lines of force between the poles of a magnet, and as in the case of the magnet the intensity of the action decreases very rapidly with distance from the source. This method was therefore of very limited application, for it entailed the use of at least twice as much wire as would have served to connect the stations directly, had that been possible. The long base lines required between the earth-plates at both the transmitting and receiving stations precluded entirely its use for communication between ship and shore. The Helsby Cymophone is almost the only modern system which depends on this principle, and, though pairs of earth-plates are used, the transmitting and receiving instruments have been so much developed in power and sensibility that the ratio of the distance between transmitter and receiver to the distance between either pair of *connected* earth-plates has been much increased.

---

* See "History of Wireless Telegraphy," by J. J. Fahie.

Sir W. Preece, also, employs earth-plates at the ends of elevated horizontal wires, and though the actual process of transmission is somewhat different its limitations are similar. This system has, however, been of use under certain circumstances, and there are a few installations working in the United Kingdom.

Open Circuit Wireless Telegraphy.—Leaving then these systems in which the lines of electric force are moving at right angles to the direction of transmission, and in which the intensity of their action therefore falls off approximately as the cube of the distance, let us consider the more modern systems in which the lines of force move in the direction of transmission, and have an intensity which decreases in simple proportion to the distance. This difference constitutes in itself so enormous an advantage in favour of the single earth connection and vertical wire as opposed to the long horizontal wire earthed at both ends, that the progress of systems depending on the latter has been entirely eclipsed by the development of the former. In this book I shall therefore deal almost exclusively with the types of apparatus based on the work of Hertz, Lodge, Jackson, Trouton, Marconi, and their many followers, and not with wireless telephony, or with any closed circuit system.

We must now consider the experimental discoveries previous to the invention of modern wireless telegraphy, but on which it is based. These may be conveniently divided into (1) those which rendered the production and transmission of electric oscillations possible; and (2) those which made the detection of these oscillations easy. In the former category the researches of Henry, Von Bezold, Hertz, Lodge, and Tesla stand pre-eminent, and in the latter the principal workers were Hughes, Calzecchi-Onesti, Branly, Lodge, and Rutherford.

Henry.—Professor Joseph Henry, of Princeton University, was the first to show experimentally that the discharge of a Leyden jar may be oscillatory in character, a discovery which bears directly on the invention of wireless telegraphy, not only on account of the production of a succession of waves, but also because the changes of potential are so much more rapid than in a steady discharge. In 1838 Henry even succeeded in demonstrating that the oscillations in a circuit containing a Leyden jar and spark-gap would induce currents in an independent circuit many feet distant. Electric telegraphy was, however, in its infancy, and no attempt was made to adapt the apparatus to the needs of practical communication. Henry's observations on the oscillatory character of the discharge were confirmed experimentally by Helmholtz and Feddersen, and their theory was given by Lord Kelvin (see Chapter XVI.).

Professor D. E. Hughes.—In 1879 Hughes showed that it was possible to transmit signals without the use of a connecting wire, from an induction coil to a microphone several hundred yards away. He rightly believed that the oscillations were propagated through the insulating medium between the instruments, but discouraged by the scepticism of several well-known persons who formed a committee of inquiry, he did not continue his work beyond the purely experimental stage. The facts, though known to the committee, were not published until over twenty years later, when Marconi had already brought out his well-known system.

Sir Oliver Lodge.—While studying the nature of the spark discharge from condensers, Sir Oliver Lodge* discovered that it was possible, by equalising the electrical dimensions of two circuits, to obtain an electrical effect corresponding to the resonance of two mechanical vibrators of equal frequency. The phenomenon is of great importance in modern wireless telegraphy, and though in its original form the apparatus used did not suggest a practical means of communication, a similar arrangement of mutual equifrequent circuits forms an important part of almost every wireless telegraph instrument. It is therefore worth while to consider carefully the actual experiments as originally carried out. I shall therefore quote Sir Oliver Lodge's description :—

> "I shall show this [electrical resonance] in a form which requires great precision of tuning or syntony, both emitter and receiver being persistently vibrating things giving some thirty or forty swings before damping has a serious effect. I take two Leyden jars with circuits about a yard in diameter, and situated about two yards apart (Fig. 6). I charge and discharge one jar, and observe that the surgings set up in the other can cause it to overflow if it is syntonised with the first (see *Nature*, vol. xli., p. 368 ; J. J. Thomson, 'Recent Researches,' p. 395). A closed circuit such as this is a feeble radiator and a feeble absorber, so it is not adapted for action at a distance. In fact I doubt whether it will visibly act at a range beyond the $\frac{1}{4}\lambda$ at which true radiation of broken-off energy occurs. If the coatings of the jar are separated to a greater distance, so that the dielectric is more exposed, it radiates better; because in true radiation the electrostatic and the magnetic energy are equal, whereas in a ring circuit the magnetic energy greatly predominates. By separating the coats of the jar as far as possible we get a typical Hertz vibrator (Fig. 6A), whose dielectric extends out into the room, and thus radiates very powerfully."

As means of communication, systems based on the interaction of two closed resonating circuits cannot compete favourably with open circuit systems, for the energy transmitted shows an exceedingly rapid decrease with distance. The fact that the possibility of producing electrical resonance had been experimentally demonstrated was, however, of fundamental importance, and opened up the way for further experiment. Many peculiarities of alternating currents of very high frequency were first pointed out by Lodge. Following an observation of Faraday's in a simple yet remarkable experiment, he showed that the self-induction of a single loop of thick wire a few feet in diameter, was so great a hindrance to an oscillating current of high frequency that a spark of considerable length, indicating a difference of potential of thousands of volts, passed across from one point on the loop to another, though the conductor forming the loop had a resistance of only a small fraction of an ohm.

---

* *Nature*, vol. xli., p. 368, Feb. 1890.

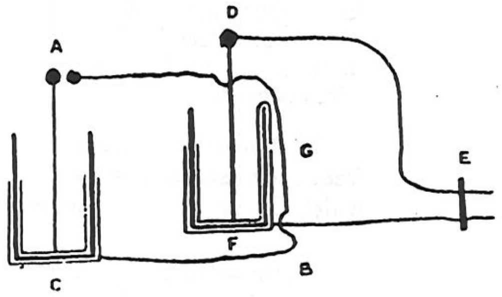


FIG. 6.—LODGE'S SYNTONIC LEYDEN JAR CIRCUITS.

A, B, C, Transmitting Circuit; *D, E, F*, Receiving Circuit; *A*, Spark-Gap; *E*, Slider for Tuning by altering Receiving Circuit; *G*, Small Overflow Spark-Gap for detecting Received Current.

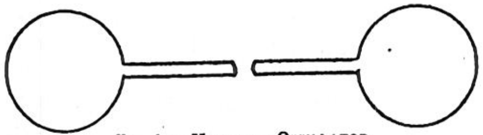


FIG. 6A.—HERTZIAN OSCILLATOR.

The enormous importance of the inductance of any circuit along which it is proposed to send high frequency currents can hardly be over-estimated by those accustomed to work with currents of low frequency.

A few examples of the calculation of the impedance of a circuit for currents of different frequencies will be found in the tables at the end of this book.

Capacity plays an equally important part in wireless telegraphy, and is never a negligible factor. Indeed most problems in the subject resolve themselves into questions concerning the capacity, inductance, and therefore the geometrical form of the conductors concerned. The material of the conductor is generally of secondary importance, but its size and shape and the dielectric properties of the insulating material surrounding it determine the distribution of the lines of electric force, and, if these are in motion, the system of magnetic lines which constitutes the self-induction or inertia of the circuit. The actual form of the circuit is thus of more importance than the material of which it is composed.

Von Bezold.—Von Bezold,* in 1870, discovered that electric currents or impulses are reflected from the insulated end of a conductor, and obtained nodes and loops of potential at different points on a wire. He was at the time experimenting with the well-known Lichtenberg dust figures. If a glass plate be covered on one side by tinfoil which is connected to earth, a discharge from the end of a conductor placed near the middle of the other side, leaves the bare surface of the glass electrified. Dust is then shaken over the surface and adheres to the glass in peculiar seaweed-like patterns, the forms of which for positive and for negative discharges are quite different in character. It is thus possible to distinguish a positive from a negative discharge though either may last only for a very minute fraction of a second.

---

* Poggendorf's *Annalen*, 140, p. 541, or "Electric Waves," Hertz, p. 54 (Macmillans). The following excerpts and diagrams, Figs. 7-13, are inserted by kind permission of Messrs Macmillan and Dr J. A. Barth, of Leipzic.

The discovery of nodes on a conductor carrying oscillatory currents was made by means of the apparatus shown diagrammatically in Fig. 7.

By varying the lengths of the loops of wire D and D′, it was found that the dust figures produced at B disappeared, while those at A and C were strongly developed. A, B, and C were all equally near to the tinfoil earth-plate, but the result showed that the potential at B did not rise; while at A, which was earthed through a high resistance of great self-induction—what we would now call a choking coil—and at C, the completely insulated end, there existed loops of potential.

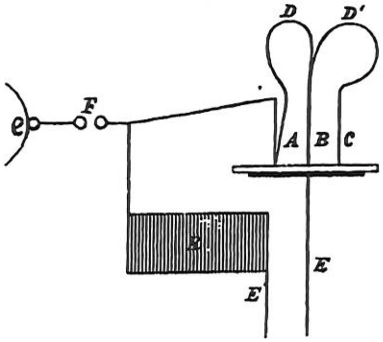


Fig. 7.

The reflection of electric waves from the insulated end of a conductor was thus proved by the production of stationary nodes and loops of potential and the existence of a finite velocity of propagation established.

The result of this research was probably the first experimental confirmation of Maxwell's theory of the propagation of electric disturbances, since it was now shown that their speed of propagation was finite.

Von Bezold sums up his results as follows:—

"1. If, after springing across a spark-gap, an electric discharge has before it two paths to earth, one short and the other long, and separated by a test plate, the discharge current splits up, so long as the sparking distance is small; but when it is larger the electricity rushes solely along the shorter path carrying with it, out of the other branch, electricity of the same sign.

"2. If a series of electric waves is sent along a wire which is insulated at the end, the waves are reflected at the end, and the phenomena which accompany this process in the case of alternating discharges appear to be caused by interference between the advancing and reflected waves.

"3. An electric discharge traverses wire of equal lengths in equal times whatever may be the material of which these wires consist."

It should be noticed that Von Bezold produced high frequency oscillations by the use of a spark-gap, a method which has not yet been superseded.

Hertz.—Eighteen years later Hertz published an account* of his experiments on the propagation of electric waves along wires. Though some of his conclusions have had to be modified in view of later knowledge, they are yet of such fundamental importance that we must summarise them:—

1. He shows that Faraday's view that electric forces are electric polarisations existing independently in space is confirmed by his experiments.

2. It is proved that the velocity of propagation of electric force in space is finite.

We now come to the series of experiments on which the fame of Hertz chiefly rests. As is usual in such cases, they did not originate in a sudden inspiration or happy accident, but were the continued development of the same theme by a mind endowed with wonderful insight, perseverance, and constructive imagination.

During the experiments described above he had often noticed that sparks appeared in the secondary circuit when it was in positions in which no direct action was possible, and in particular near walls or other bodies which might be supposed capable of reflecting the inductive action.

---

* Wiedemann's *Ann.* 34, p. 551.

The simplest explanation appeared to be that the induction actually spread out as waves from the wire, which were then reflected from the walls, and, interfering with the advancing waves, caused regions corresponding to the nodes and loops in a stationary vibration. In order to find whether free radiation was in reality taking place the conditions of experiment were made more favourable for reflection and the whole space in the neighbourhood of the radiator thoroughly explored.

The radiator, which consisted, as in the last experiments, of two square brass plates, 40 by 40 cm., connected by a copper wire 60 cm. long, with a spark-gap at its middle point, was set up vertically at 13 m. distance from a wall on the face of which was a large sheet of zinc to act as reflector. The secondary conductor was, as before, a ring of wire of 35 cm. radius, which was mounted on a wooden stand capable of rotation about a vertical and a horizontal axis, and at one end of the horizontal axis there was a small adjustable spark-gap in the circle of wire. It was by the occurrence of minute sparks at this gap that the inductive action was observed, and the positions of the loops and nodes caused by the interference of the direct and reflected waves mapped out. At least this was the explanation which occurred to Hertz, and though it has been in some respects modified by the researches of Bjerknes and other experimenters, the main facts which he demonstrated, viz., (1) that true electro-magnetic waves, travelling as a free radiation through the dielectric may be generated by oscillatory currents on a conductor, and that (2) the velocity of these waves is finite, have been entirely confirmed by later researches.

Clerk-Maxwell had stated his belief in the existence of such waves, and had given, in part iv., chapter xx., of his treatise on "Electricity and Magnetism," the fundamental

laws of their motion; but it was reserved for Hertz to give an experimental proof of their reality and to discover methods for their production and detection.

Hertz now proceeded to show that the waves produced by his oscillator were in all respects light waves of great length—that, in fact, they obeyed all the known laws of the propagation of light. This was not accomplished with the original oscillator, since the waves it produced were several metres long, rendering necessary the use of excessively large reflectors and prisms to deal with them. A much smaller oscillator was therefore made which gave out a wave of about 60 cm. This apparatus consisted of two thick brass rods with a short spark-gap between them, placed along the focal axis of a cylindrical parabolic mirror of sheet metal. The receiver was somewhat similar in shape, and was also placed in the focal line of a mirror. It had an adjustable spark-gap for detection of the induced oscillations.

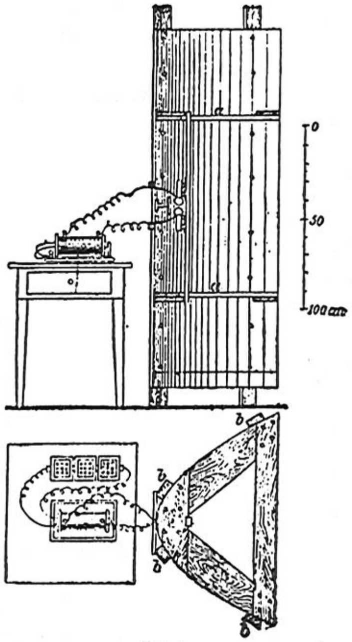


Fig. 8.

With this apparatus it was possible to demonstrate, by using a flat sheet of metal 2 m. square, that the waves followed the law of reflection, *i.e.*, that their angle of reflection from the mirror was equal to their angle of incidence. It was also shown that if the axis of the receiving mirror were horizontal while the transmitter was vertical, no sparks were visible in the former, thus proving, as was to be expected; that the waves emitted were plane polarised. This conclusion was confirmed by placing a grid of parallel copper wires in the path of the ray. Both transmitter and receiver being placed with their axes vertical, if the wires of the grid were also vertical it formed a perfect screen, nothing being observable at the receiver; but if the wires were horizontal, *i.e.*, perpendicular to the axes of the mirrors, transmission was practically as good as if there were no grid there.

In the first position it was found by experiment that the action of the grid was not merely absorption, but that a large proportion of the radiation was reflected from it as from a plane mirror. In this respect the phenomenon differs from the action of a tourmaline plate on light, since the tourmaline absorbs what it does not transmit.

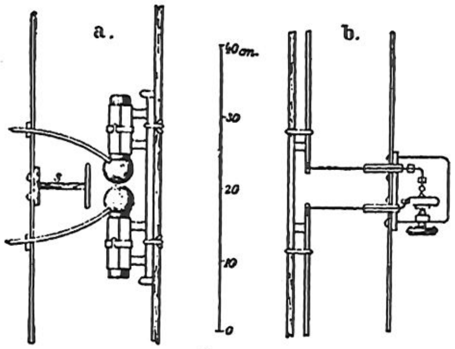


FIG. 9.

A large prism of pitch, having as a base an isosceles triangle of 1.2 m. in the side and whose height was 1.5 m., was next constructed, and was used to determine whether the rays were refracted on passing from air into a medium of different refrangibility. The angle of the prism was about 30°. It was found that the ray deviated about 22° on entering or leaving the prism; as the angle of the prism was 30° the refractive index of the pitch was therefore 1.69, a value which is within 5 per cent. of its refractive index for ordinary light.

Thus Hertz showed that free electric waves exist, and that light, as Clerk-Maxwell had foretold, is merely a manifestation of them.

The following is from Hertz's description of the form and propagation of the electric waves :*—

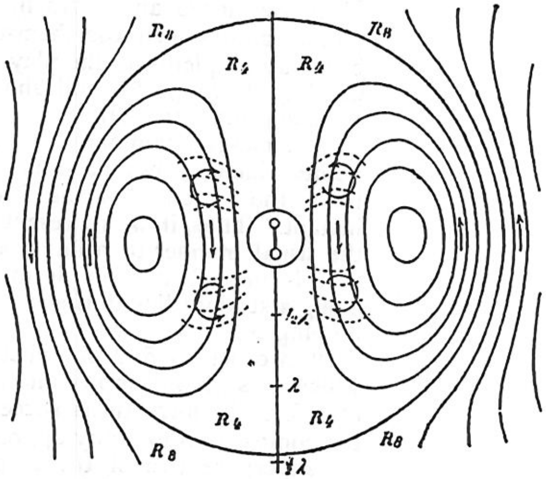
"We shall content ourselves with considering the results of the construction as shown in Figs. 10, 11, 12, and 13. These figures exhibit the distribution of force at the times, $t=O$, $\frac{1}{4}T$, $\frac{1}{2}T$, $\frac{3}{4}T$, or by a suitable reversion of the arrows for all subsequent times which are whole multiples of $\frac{1}{4}T$. At the origin is shown, in its correct position and approximately to correct scale, the arrangement which was used in our earlier experiments for exciting the oscillations. The lines of force are not continued right up to this picture, for our formulæ assume that the oscillator is infinitely short, and therefore became inadequate in the neighbourhood of the finite oscillator.

"Let us begin our explanation of the diagrams with Fig. 10. Here $t=O$; the current is at its maximum strength, but the poles of the rectilinear oscillator are not charged with electricity—no lines of force converge towards them. But from the time $t=O$ onwards, such lines of force begin to shoot out from the poles; they are comprised within a sphere represented by the value $Q=O$. In Fig. 10, indeed, this sphere is still vanishingly small, but it rapidly enlarges, and by the time $t=\frac{1}{4}T$ (Fig. 11) it already fills the space R. The distribution of the lines of force within the sphere is nearly of the same kind as that corresponding to a static electric charge upon the poles. The velocity with which the spherical surface $Q=O$ spreads out from the origin is at first much greater than $1/A$; in fact, for the time $\frac{1}{4}T$, this latter velocity would only correspond to the value of $\frac{1}{4}$ given in the figure. At an infinitesimal distance from the origin the velocity of propagation is even infinite.

---

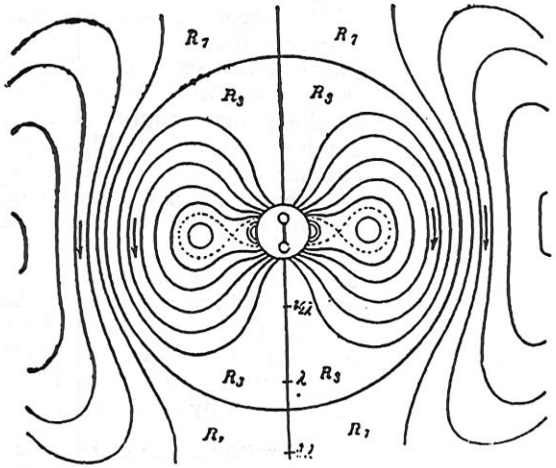
* "Electric Waves," Hertz, p. 146, translated by D. E. Jones (Macmillan). Inserted by kind permission of Messrs Macmillan and Dr J. A. Barth.

i = [illegible]
charge [illegible] = 0
no [illegible] force



R_8
R_8
R_4
R_4
$\frac{1}{2}\lambda$
λ
R_4
R_4
R_8
R_8
$1\frac{1}{2}\lambda$

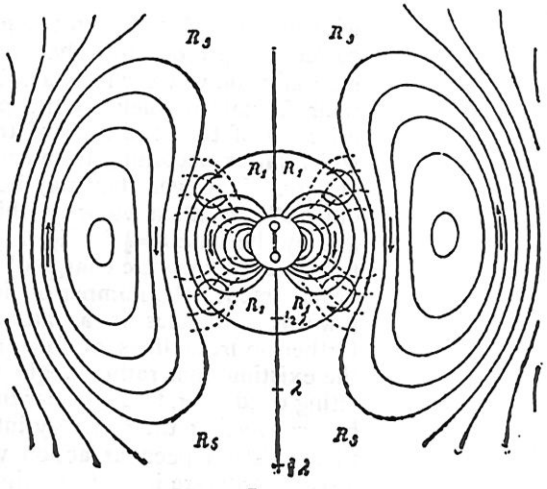
FIG. 10.



R_7
R_7
R_3
R_3
$\frac{1}{2}\lambda$
R_3
λ
R_3
R_7
R_7
$1\frac{1}{2}\lambda$

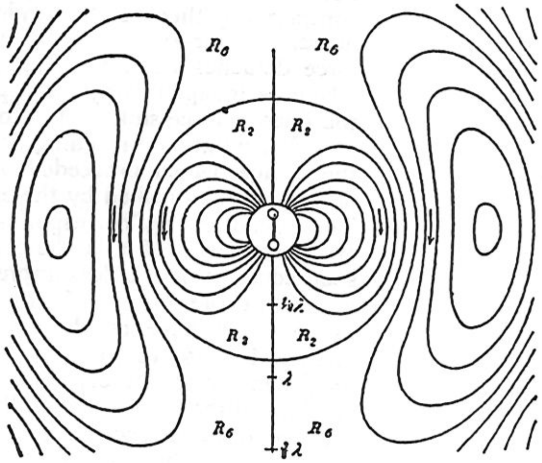
FIG. 13.

"This is the phenomenon which, according to the old mode of expression is represented by the statement that



R_5
R_5
R_1
R_1
R_1
R_1
$\frac{1}{2}\lambda$
λ
R_5
R_5
$1\frac{1}{2}\lambda$

FIG. 11.



R_6
R_6
R_2
R_2
$\frac{1}{2}\lambda$
R_2
R_2
λ
R_6
R_6
$1\frac{1}{2}\lambda$

FIG. 12.

[illegible] in

upon the electro-magnetic action which travels with the velocity 1/A, there is superposed an electrostatic force travelling with infinite velocity. In the sense of our theory we must correctly represent the phenomenon by saying that fundamentally the waves which are being developed do not owe their formation solely to the processes at the origin, but arise out of the conditions of the whole surrounding space, which latter, according to our theory, is the true seat of the energy. However this may be, the surface $Q=O$ spreads out further with a velocity which gradually sinks to $1/A$, and by the time $t=\frac{1}{2}T$ (Fig. 12) fills the space R_2. At this time the electrostatic charge of the poles is at its greatest development; the number of lines of force which converge towards the poles is a maximum. As time progresses further no fresh lines of force proceed from the poles, but the existing ones rather begin to retreat towards the oscillating conductor, to disappear there as lines of electric force, but converting their energy into magnetic energy. Here there arises a peculiar action which can plainly be recognised, at any rate in its beginnings, in Fig. 13 ($t=\frac{3}{4}T$). The lines of force which have withdrawn furthest from the origin become laterally inflected by reason of their tendency to contract together; as this inflection contracts nearer and nearer to the z-axis, a portion of each of the outer lines of force detaches itself as a self-closed line of force which advances independently into space, while the remainder of the lines of force sink back into the oscillating conductor.

"The number of receding lines of force is just as great as the number which proceeded outwards, but their energy is necessarily diminished by the energy of the parts detached. This loss of energy corresponds to the radiation into space. In consequence of this, the oscillation would of necessity soon come to rest unless impressed forces restored the lost energy at the origin. In treating the oscillation as undamped, we have tacitly assumed the presence of such forces. In Fig. 10 to which we now return for the time $t=T$, conceiving the arrows to be reversed—the detached portions of the lines of force fill the spherical space R_4, while the lines of force proceeding from the poles have completely disappeared. But new lines of force burst out from the poles and crowd together the lines whose development we have followed into the space R_5 (Fig. 11). It is not necessary to explain further how these lines of force make their way to the spaces R_6 (Fig. 12), R_7 (Fig. 13), R_8 (Fig. 10).

They run more and more into a pure transverse wave-motion, and as such lose themselves in the distance. The best way of picturing the play of the forces would be by making drawings for still shorter intervals of time and attaching these to a stroboscopic disc.

"A closer examination of the diagrams shows that at points which do not lie either on the z-axis or in the xy-plane the direction of the force changes from instant to instant. Thus, if we represent the force at such a point in the usual manner by a line drawn from the point, the end of this line will not simply move backwards and forwards along a straight line during an oscillation, but will describe an ellipse.

"In order to find out whether there are any points at which this ellipse approximates to a circle, and in which, therefore, the force turns successively through all points of the compass without any appreciable change of magnitude, we superpose two of the diagrams which correspond to times differing by $\frac{1}{4}T$ from one another, *e.g.*, Fig. 10 and Fig. 12, or 11 and 13. At such points as we are trying to find, the lines of the one system must clearly cut those of the second system at right angles, and the distances between the lines of the one system must be equal to those of the second. The small quadrilaterals formed by the intersection of both systems must therefore be squares at the points sought. Now, in fact, regions of this kind can be observed; in Figs. 10 and 11 they are indicated by circular arrows, the directions of which at the same time give the direction of rotation of force. For further explanation dotted lines are introduced which belong to the system of lines in Figs. 12 and 13. Furthermore we find that the behaviour here sketched is exhibited by the force not only at the points referred to, but also in the whole strip-shaped tract which, spreading out from these points, forms the neighbourhood of the z-axis. Yet the force diminishes in magnitude so rapidly in this direction that its peculiar behaviour only attracts attention at the points mentioned."

From these researches has sprung modern wireless telegraphy, and though free radiations are no longer generally used, Marconi, among others, drew his original inspiration from Hertz, his first essay at wireless telegraphy being the invention of a telegraphic receiver which could detect and record as Morse signals the arrival of waves from a Hertz transmitter of the form we have described.

In 1894, at a lecture in the Royal Institution, Sir Oliver Lodge showed how the coherer might be utilised for the detection of Hertzian waves up to a distance of about 150 yards. The receiver, however, could hardly be called a telegraph instrument, and the possibility of developing it into one was apparently at the time hardly realised by the lecturer. His syntonic system, patented in 1897, will be described later.

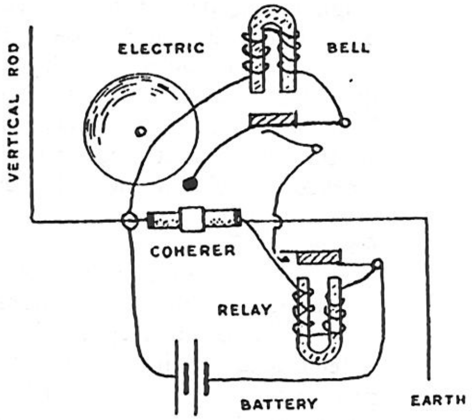


Fig. 14.—Popoff's Receiver.
The hammer strikes the gong and coherer alternately, decohering the latter after each impulse.

Early in 1895 Professor Popoff of St Petersburg described a system of observing atmospheric electricity by means of a lightning rod connected through a coherer to earth. A relay and local battery were put in circuit with the coherer, and the relay in turn closed the circuit of an electric bell. This arrangement, which resembles Lodge's receivers of 1890 and 1894, Popoff proposed in December 1895 to use for telegraphic purposes, if a sufficiently powerful generator of electric waves could be found to serve as transmitter. It was apparently not until after Marconi's success had become known that Professor Popoff discovered the necessary transmitter. Fig. 14 shows, diagrammatically, the arrangement for detecting electrical disturbances which it was proposed to use as a telegraphic receiver. The system is now in use in France and Russia.

Nikola Tesla.—It is impossible to leave the part of our subject which is concerned with the fundamental discoveries on which wireless telegraphy is based without taking account of some of the brilliant inventions and schemes of Tesla. Though much that has been attributed to him has undoubtedly had its origin in the prolific imagination of the American Press, there remains an exceedingly substantial basis of fact, mostly in the form of patent specifications, or of actual lecture demonstrations, which shows his extraordinary inventive power and wonderful knowledge of the properties of alternating currents of both low and high frequency.

Among many other inventions, made as early as 1893, perhaps the most important to wireless telegraphists is his method of producing long trains of waves of high frequency, and of transforming them to higher voltage. After several unsuccessful attempts he completed an alternator which could be run at 30,000 periods per second, and designed a form of transformer capable of transforming these currents to very high voltage. He also showed that his transformer, or "Tesla coil," as it is usually called nowadays, could transform currents of much higher frequencies than were obtainable from his alternator, even currents of 100,000 or 1,000,000 periods per second, such as are produced by the oscillatory discharge of a Leyden jar. Fig. 15 shows the apparatus used.

Even at low voltages high frequency currents show many remarkable peculiarities, most of which are not noticeable in ordinary alternate current working, unless in very exceptional circumstances. The heating effect of a high frequency current is, for instance, enormous owing to its limitation to a thin skin on the surface of the conductor. The hysteresis losses in iron placed in so rapidly alternating a field are also very great. Thus Tesla found that the temperature of an iron wire $\frac{1}{16}$ inch in diameter inside a coil of 250 turns, in which a current estimated at 5 amperes was flowing, rose about 500° C. in two seconds.

At very high frequencies the presence of an iron core in a coil did not appreciably add to its self-induction, an interesting fact of immediate application in wireless telegraphy.

Remarkable effects may be produced by adjusting the capacity and inductance of a high frequency circuit. Thus, Tesla found that if a condenser be included in the circuit, the potential at its terminals may rise far above that of the alternator. That similar effects are not in any appreciable degree noticeable with lower frequencies is probably due to the enormous condensers that would be required in order to obtain electrical resonance (revibration) at the low frequencies which are used in the distribution of electrical energy. To determine the actual size of condenser which would be required in this case, let us assume that an inductance, of low resistance, such as the series windings of the field magnets of a traction motor, is available, and then find by calculation the capacity which must be added to give a natural frequency of 50 periods per second to the circuit.

The natural frequency of an electric vibration in a circuit of capacity C, microfarads, and inductance, L, cms., is given by the equation—

$$n = \frac{5{,}000{,}000}{\sqrt{CL}}$$

If we take $L = 10^8$ cm., and $n = 50$, we find C approximately equal to 100 microfarads. If exactly adjusted to equi-frequency with the alternator, the circuit would exhibit resonance effects on an extraordinary scale.

Let us return, however, to Tesla's experiments, the results of which throw a flood of light on many points in wireless telegraph working which would otherwise be hard to understand. When a high frequency current is passed through the primary of a step up transformer the voltage is greatly increased, and many new phenomena are observable. Powerful brush and flame discharges are given off by conductors connected to the terminals, the neighbouring air being actually rendered quite warm by the intense molecular bombardment, even though the frequency be not above 10,000 per second. With a frequency ten times as great as this the effects are much more marked; to obtain them, however, an alternator is not sufficient, the greatest frequency Tesla obtained by such means being about 30,000 per second. An induction coil was therefore used, which charged a Leyden jar. The latter discharged itself across a spark-gap through the primary of an air-cored transformer. The discharge of the jar being oscillatory, the currents induced in the secondary of the transformer were of much higher voltage, but of the same frequency. At so great a frequency the impedance of even a thick short conductor is so large, that differences of potential amounting to hundreds of volts may be maintained at points quite near together; nodes and loops of potential, which may be located by means of an ordinary glow lamp, also appear on the conductor.

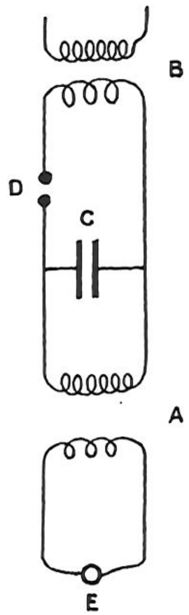


FIG. 15.—THOMSON-TESLA TRANSFORMER FOR PRODUCING HIGH FREQUENCY ALTERNATING CURRENTS OF HIGH VOLTAGE.

A, Transformer; *B*, Special Transformer; *C*, Condenser; *D*, Spark-Gap; *E*, Alternator.

The transformer used to produce these effects was of necessity very different from the ordinary article of commerce. The primary consisted of a few turns of thick copper wire inside a glass tube. No iron core was used, as with such high frequencies the magnetic induction does not penetrate the iron, and thus no advantage would be

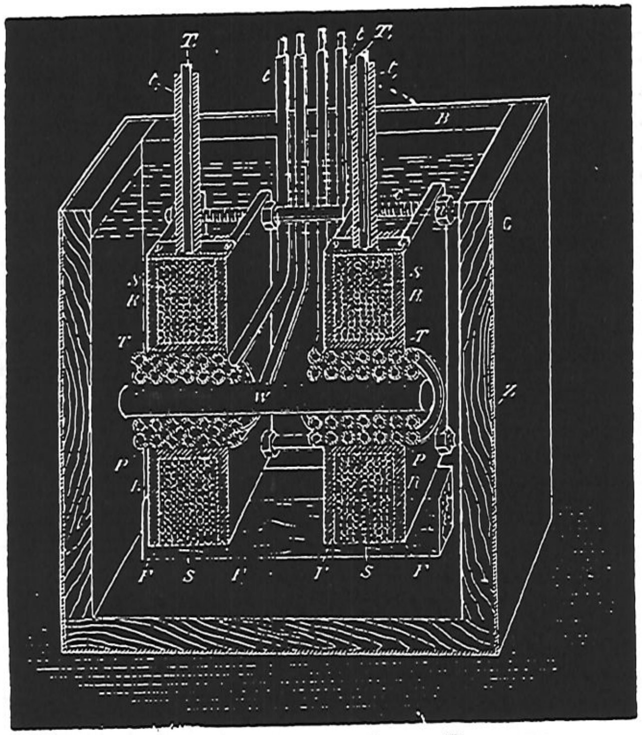


FIG. 16.—TESLA'S HIGH FREQUENCY CURRENT TRANSFORMER.
P, Primary of G.P. covered wire; *S*, Secondary; *R*, *R*, Bobbins containing Secondary.

gained. Outside the glass tube were two small bobbins, wound with guttapercha-covered copper wire. The number of turns was not great, as the rise of voltage depends mainly on resonance in the secondary circuit, and not directly on the ratio of the numbers of turns in the primary and

secondary. The whole transformer was sunk in a bath of insulating oil from which air had been removed by means of a pump. In order to get the maximum effect the frequency of the secondary circuit is adjusted to that of the primary by altering its capacity. This may be done by means of a small condenser, or by merely altering the size of the spheres which form the secondary terminals. Tesla has shown that in dealing with these currents, liquid dielectrics are far preferable to solids as insulators. The molecular bombardment heats the surface of a solid, or the gas contained in any cavity of it, so rapidly, that it soon loses its insulating properties. Oil, free from air, gives three or four times as good results as the best solid insulator, and has the advantage that if a disruptive discharge should occur through it, the puncture is self-sealing.

A transformer circuit of this type is in use in almost all wireless telegraph stations for the production of the electric waves of high frequency and voltage which are used in the transmission of signals.

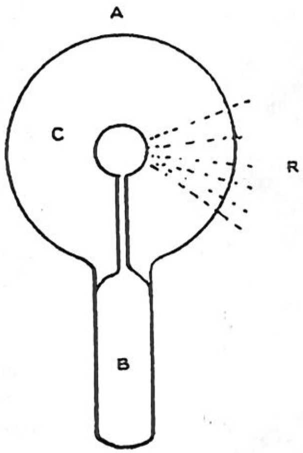


FIG. 17.—THE SENSITIVE RAY.
A, Outside Glass Bulb (High Vacuum); *B*, Inner Bulb (Low Vacuum), connected by tube with *C*; *R*, Sensitive Rays.

One very curious phenomenon—which Tesla suggests may be useful in wireless telegraphy, but which (as far as the writer is aware) has not yet been so employed—remains to be mentioned. It may be called the sensitive ray. A small spherical glass bulb, on a tubular stem, is sealed into a larger spherical bulb. The space between the bulbs is very highly exhausted, and the air in the small bulb and stem is rarified just sufficiently to make it conductive. If one terminal of the H.F. transformer is connected to the air in the stem, a soft light appears round the central sphere. In time this diffuse radiation condenses into a definite ray which is extremely sensitive to both electric and magnetic influence. A small permanent magnet only 2 cm. in length will affect the ray at a distance of several metres, and the mere presence of a conducting body in the neighbourhood of the bulb causes the ray to move so that it is always turned away from the conductor. Unfortunately this condition is not permanent, though when the phenomenon is properly understood means may be found to make it so. The discovery was made fully a dozen years ago, before wireless telegraphy had become practical; perhaps it may some day be revived and form part of a peculiarly sensitive receiver.

The Superposition of Small Periodic Motions.—A favourite lecture experiment of Lord Kelvin's was to show the gradual increase in the amplitude of the swing of a long and heavy pendulum when its bob is struck with a very small mass, at the times when it reaches the limit of each swing. A factory has been known to collapse through the motion of the engine getting into time with the natural period of vibration of the structure. Both are illustrations of a general principle of immense importance in nature, and of paramount importance in the working of a wireless system.

In wireless telegraphy the two great desiderata are the ability to transmit messages to great distances, and to prevent interference between neighbouring stations. The solution of both problems depends mainly on the principle of the superposition of small periodic motions. In order that this principle may be successfully applied it is necessary that the oscillations should continue, with little diminution of amplitude for many complete periods, *i.e.*, that the damping should be slight. Damping or decrease of amplitude is due to two causes—firstly, to dissipation of energy, as heat, in the local circuits; secondly, to radiation. The first may be reduced to a minimum by properly proportioning the resistance, capacity, and inductance of the circuits, but the second is inevitable, as it represents the energy transmitted outwards, a portion of which actuates the distant receiver.

Now the action of a receiver usually depends on the amplitude of the oscillation of potential excited in it by the waves from the transmitting station. If these consist, as in Marconi's untuned system of one wave of large amplitude with a train of three or four rapidly diminishing waves behind it, it is clear that the reception of signals depends mainly on the amplitude of the first wave and that the energy of the others is quite negligible in comparison. If, however, a long train of very slowly diminishing waves be sent out, the effect of each, if the receiver be properly constructed, will be added to that of those before until an oscillation of great amplitude is induced in the receiver. It is more easy to transmit a large amount of energy by a succession of small waves than by one large one, for the latter would involve excessively high voltage and current. Hence the

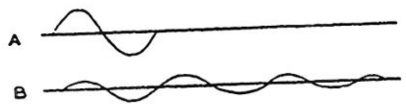


FIG. 18A.
A, Transmitted Wave; *B*, Oscillatory Current produced in Receiver.

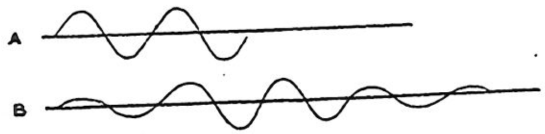


FIG. 18B.
A, Two Waves Transmitted; *B*, Resultant Current in Receiver, showing growth through superposition of impulses.

advantage, in long-distance transmission, of using transmitters and receivers whose natural frequencies are equal. Thus if the frequencies of the electrical vibrators at both stations be the same and the local dissipation of energy very small, it is possible to communicate by using long trains of waves of moderate voltage. Distances may be covered in this manner which would be impracticable if transmission depended on a single wave or impulse.

It is fortunate that the best conditions for the transmission of signals are also those which render it possible to arrange for the non-interference of neighbouring stations. If a receiver only acts after a considerable number of properly timed waves have arrived, we may arrange that it is not actuated by other transmitters by causing these to give out waves of frequencies other than that to which the receiver responds. The weak point of this system of discrimination between stations is that the receiver may respond to trains of waves of slightly greater or less frequency than its own. A certain margin must therefore be allowed for each station in the matter of frequency, and therefore the number of non-interfering stations in a neighbourhood is not unlimited. This question has been recently discussed by J. J. Hettinger,[*] who has determined the limits of non-interference of two stations.

If a piece of elastic material, such as a metal rod, or the column of air in an organ pipe, be caused to vibrate, it has been found that the motion tends to take certain definite forms. Thus a stretched string will vibrate as a whole, the only parts not in motion being the fixed ends. This is called its fundamental vibration. Or it may have a quiet point at its middle while the rest of its length is in motion. This mode of vibration is called the first harmonic, or octave (or sometimes the second harmonic). Its frequency is double that of the fundamental vibration. In like manner the vibrating body may move in 3, 4, 5, or any number of equal segments; the corresponding frequencies of the emitted waves being 3, 4, 5, or *n* times that of the fundamental vibration. The motion of the electricity on an electrical vibrator, by which is meant a conductor, or combination of conductors, bounded by a dielectric which reflects the electrical surges back on themselves from the ends of the conductor and so maintains a "stationary" vibration of definite period, follows a similar law, the frequency of the vibration being proportional to the number of segments in which it takes place.

Electrical engineers have recently had this subject of harmonic vibration brought very clearly before them through the study of alternate currents by means of Duddell's Oscillograph; and though the harmonics in this case are as a rule forced and not due to natural resonance, the compound waves obtained are of the same character as those formed by the synthesis of natural harmonics. A few types of compound waves are shown in Fig. 19.

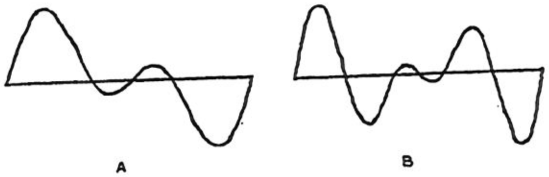


FIG. 19.—COMPLEX PERIODIC VIBRATIONS.
A, Fundamental and First Overtone (Frequencies, 1 : 2); *B*, Fundamental and Second Overtone (Frequencies, 1 : 3).

The various phenomena connected with the production of stationary electric waves on wires have been very fully elucidated by a number of experimenters. Among many others of lesser importance, the names of Von Bezold, Lodge, Hertz, Sarasin and De la Rive, and Barton[*] may be mentioned. Their researches have proved that the rate of propagation of waves of high frequency along wires is practically the same as the velocity of light, *i.e.*, about 3×10^{10} cm. per second. In wireless telegraphy we have to deal with waves which travel outwards from a centre along a nearly plane conductor as well as with waves along wires; the theory of the former is not so well understood, most of our knowledge of the subject is therefore rather qualitative than quantitative. In long-distance transmission we have also to take into account the conductivity of the rarified air of the upper atmosphere, which may reduce the propagation of the waves to the case of two concentric spherical conductors. These questions will be considered in a later chapter.

---

[*] *Electrical Review*, 1906.

[*] *Phil. Mag.*, May 1899.

Rutherford.—In 1896 Professor E. Rutherford, using a large horizontal Hertzian radiator as transmitter, and his magnetic detector with short unearthed conductors as receiver, obtained signals at distances of over a mile.

CHAPTER II.

EARLIER ATTEMPTS AT WIRELESS TELEGRAPHY.

HAVING briefly described in the last chapter the experimental researches which showed the way to the invention of modern high frequency wireless telegraphy, we must now go into the actual experiments, directed definitely to the invention of a new means of communication, from which the systems now in use have sprung.

Hughes's discovery in 1879, that his microphone could detect, at a considerable distance, the oscillations radiated from a conductor connected to one side of the spark-gap of an induction coil, came before the time was ripe for such things, and as they were not published, cannot have influenced subsequent workers. They stand as a warning to the inventor against discouragement by the dicta of scientific men, who, though learned, have not gone through in detail the course of experiment and reasoning which have led him to his conclusions.

The coherer, subsequently rediscovered by Calzecchi-Onesti, Lodge, and Branly, was simply an imperfect contact like the microphone, and if Hughes's results had been published in 1879 there is little doubt that the existence of electrical radiations would have been an established fact several years before Hertz's experiments were carried out.

Probably the earliest successful attempt at communication by means of a system in which only one earth connection is used at each station was that of Professor Dolbear, who in 1882 applied for an American patent for a system of electrical communication between two or more places with-

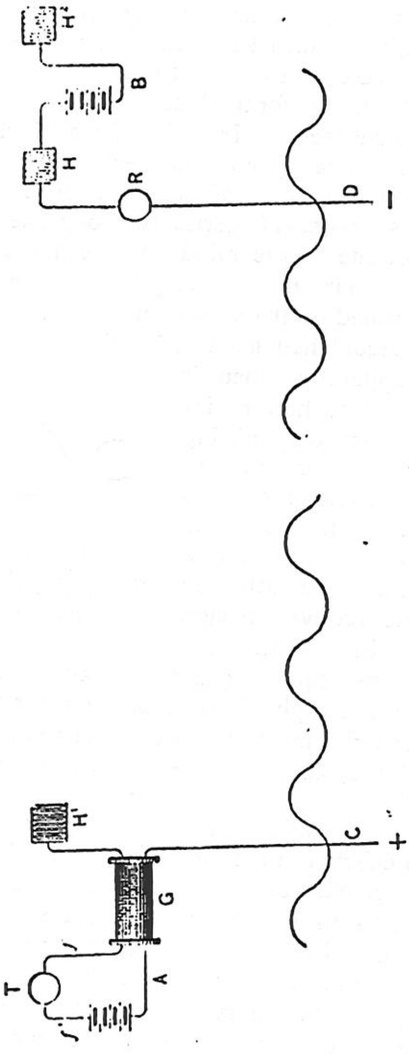


FIG. 20.—DOLBEAR'S SYSTEM. *T*, Transmitter; *R*, Receiver; *C*, *D*, Earth Connections.

out wire or conductor. In his first experiment he employed a small magneto-electric machine, *i.e.*, a producer of alternating current, as transmitter. One terminal only was earthed, the other being free and only a foot or two long.

The receiver was an ordinary telephone, one terminal being to earth and the other held in the hand of the observer, who was insulated. The distance of transmission in the first instance was about sixty feet, which was later increased by substituting an induction coil, with a Morse key in the primary circuit, for the magneto; large capacities were also attached to the free ends of the receiver and transmitter, and apparently even telephonic speech was transmitted over a distance of about half a mile. The patent specification does not greatly elucidate the theory of the system. The author states that it is of prime importance to keep the earth wires oppositely charged at transmitter and receiver, and for this purpose he attaches the positive and negative poles of primary batteries to them. What advantage this arrangement could give, when the transmission was in reality by *alternate* currents, is not at all clear. Fig. 20 shows the apparatus used on this system when intended for the transmission of speech.

Still following the chronological order, we find that in 1893 Tesla proposed a plan for the wireless transmission of electrical energy—including, of course, telegraphic messages—which, though resembling Dolbear's system in some respects, contained an important, indeed a fundamental improvement.

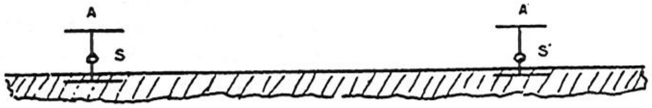


FIG. 21.—TESLA'S PROPOSED WIRELESS TELEGRAPH.
A, *A'*, Aerial Capacities; *S*, *S'*, Transmitting and Receiving Instruments.

The proposal was to use an elevated capacity and a single "earth" at each station. At the transmitter a source of alternating currents was to be employed as in Dolbear's transmitter, and at the receiver some type of instrument suitable to the frequency of the current employed. The improvement lay in the suggestion that the self-induction and capacity of the receiver should be adjusted so that its natural period of electrical vibration should be the same as that of the transmitted current. The receiver would thus revibrate to the waves received, and the oscillations generated in it grow in amplitude as they continued to arrive. A series of very slight waves of low potential would therefore be able to create, in time, an oscillation great enough to be recorded by the instrument. This suggestion grew naturally out of the inventor's discoveries of the properties of high frequency currents, but was apparently not put into practice, nor even patented, until 1897. Earlier in the same year, Sir Oliver Lodge, approaching the subject from the point of view of Hertzian radiations, had patented a system of telegraphy without wires in which Hertzian waves were employed. The transmitter was a species of Hertz oscillator, the receiver being of the same electrical dimensions (*i.e.*, capacity, &c.), and having therefore the same natural rate of vibration as the transmitter. This and Marconi's American patent of 1896 are the first patents extant for syntonic systems. Tesla's patent, based on his suggestion of 1893, was taken out somewhat later. It should be noted that he did not, like Lodge, propose to employ free radiations, but dealt with oscillating currents conducted by the earth.

Captain H. B. Jackson, R.N., in 1895, before Marconi's inventions had been published, had actually succeeded in transmitting in the Morse code between two ships by means of apparatus very similar to that simultaneously invented by Marconi. Details of Captain Jackson's apparatus have never been published, as the system is of course the property of the Navy. Professor Trouton had also experimented on a similar plan.

Marconi.—As already mentioned in the last chapter, Mr Marconi's first wireless system (patented in 1896) was based directly on Hertz's experiments. The transmitter consisted of a Hertzian oscillator placed in the focal line of a parabolic mirror and actuated by an induction coil. The receiver was also similar to that of Hertz, with the addition of a coherer as detector and an automatic arrangement for causing decoherence immediately on reception of a signal. These additions converted an apparatus which had been merely a detector of electrical waves into a telegraphic instrument which could transmit messages by their agency. Using direct radiations, Marconi succeeded with this

apparatus in communicating over a distance of about 2 km., a distance at which no previous experimenter had been able even to detect the arrival of the waves.

The Lodge form of oscillator was also used in many of the experiments. It differs from Hertz's in having two isolated metal spheres between the terminal spheres of the high tension circuit of the induction coil. There are thus three spark-gaps in series, two long ones at either end and a short one in the middle between the insulated spheres. It gives out waves of very high frequency, as its period is determined by the dimensions of the two spheres.

Marconi had not continued his experiments long with this apparatus when it occurred to him to increase its transmitting power by connecting large insulated conductors to each side of the spark-gap. Similar conductors were attached to the receiver circuit, and when finally the earth was requisitioned as one conductor, while the other was raised high above it on a pole, it was found possible to read the messages at eight or ten times the distance at which they could be received by Hertzian radiation alone.

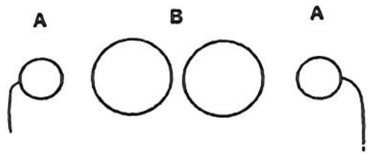


FIG. 22.—LODGE OSCILLATOR.
A, *A'*, Small Spheres connected to source of current; *B*, Large Spheres constituting Main Oscillator.
See *Nature*, vol. xli. p. 462, 1890.

The practical value of this vast improvement was at once appreciated, but the complete change which had been effected in the method of transmission by making the earth connection was by no means so quickly recognised. It seems as if the glamour of Hertz's discovery of free electric radiation has blinded the majority of physicists to the otherwise obvious fact that the elevated capacity and the earth form the oscillator, and that the receiver is situated on the oscillator itself. It is strange that the Earth should be overlooked after it has served for so many years as the return conductor for telegraphic and telephonic currents, and that there should still (1912) be persons who appear to imagine that radio-telegraphy is accomplished by *free* Hertzian waves.

Marconi's first patent includes (1) direct Hertzian radiation apparatus, and (2) oscillatory current apparatus with one terminal elevated and one to earth at each station. This latter, he remarks, is better for communicating "through or across hills and other obstacles." Figs. 23 and 24 show the general arrangement of transmitter and receiver in this case. It will be noticed that the Lodge oscillator was adhered to in the transmitter, though, in the light of later knowledge, it is clear that it no longer controlled the wave-length of the transmitted waves. The principal oscillator was now formed by the aerial capacity and the earth, and gave out oscillations of much lower frequency than the pair of spheres. The whole function of the latter was therefore to convert a little of the available energy into free radiations of very high frequency, which at very moderate distances became so dispersed as to be of no practical use in transmission. Within the course of a year, Mr Marconi, taught by experience, discarded this oscillator in favour of a single spark-gap.

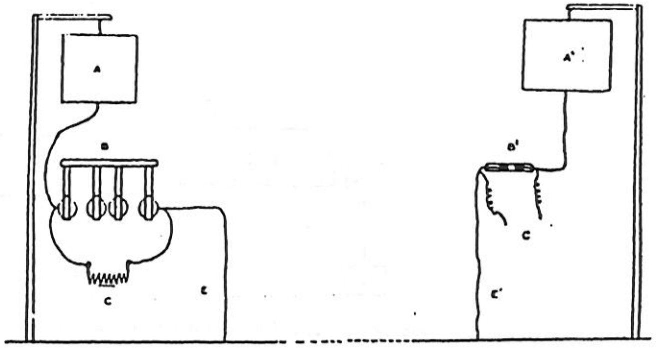


FIG. 23.—MARCONI'S EARTHED SYSTEM (Early Form).
A, *A'*, Elevated Capacities; *B*, Lodge Oscillator; *C*, Source of Current (Induction Coil); *E*, *E'*, Earth Connections; *B'*, Coherer; *C'*, Receiver Connections.

Marconi's first receiver merits description, as though

the receivers now in use contain very many new features, it was a thoroughly practical telegraphic instrument, and if in its early form it had less reliability than an ordinary telegraphic instrument, it provided a means of communication in circumstances in which the latter was totally useless.

The terminals of the coherer were connected to the wire from the otherwise insulated aerial capacity and to the earth wire. One end of the coherer was also connected to a dry cell, and the other through the magnet coil of a relay to the other terminal of the cell. In the outer circuit of the relay a battery of eight cells and an electric bell, in which the coherer took the place of the gong, were put in series. Small choking coils were inserted between the coherer and the relay circuit to prevent the oscillatory currents being dissipated in the relay, and shunts were put in parallel with all parts of the circuit in which oscillations might be generated. In parallel with the tapper circuit was a Morse inkwriter or other recording instrument. The whole receiver, except the inkwriter, was enclosed in a

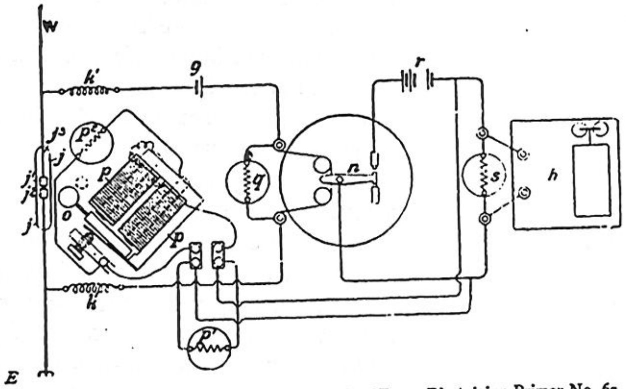


FIG. 24.—MARCONI RECEIVER (Early Form). [From *Electrician* Primer No. 67, by kind permission of the Proprietors.]
W, Aerial Wire; *E*, Earth Wire; *j*, Coherer; *o*, Tapper; *k*, *k'*, Choking Coils; *g*, Dry Cell; *n*, Relay; *r*, Battery; *h*, Morse Inkwriter; p^1, p^2, *q*, *s*, Shunts.

metal box to screen it from the action of the transmitter in the station. The box was connected to earth, the aerial wire being temporarily introduced during the reception of signals through a hole in one side. The unearthed terminal of the inkwriter was connected to the apparatus inside the box by an ingenious arrangement, which, while transmitting uni-directional currents, did not admit oscillatory currents. A length of guttapercha-covered wire was coated with tinfoil, and after being made into a coil was placed in electric contact with the outside of the box. One end of this wire was led inside, and the other connected to the inker. Direct currents, therefore, could pass along the wire, but oscillatory currents preferred to pass across from the wire to the tinfoil coating as dielectric currents, and thence *via* the surface of the box to earth. This arrangement made it unnecessary to disconnect the inker while transmitting signals from the station.

With this apparatus messages were transmitted about forty miles over Salisbury Plain, kites being used to elevate the aerial wire. A demonstration was given with the assistance of the Post Office across the Bristol Channel at Lavernock, where it is about seven miles wide, the aerials being supported by poles 150 feet high.

Experimental stations were then put up at the Needles and Bournemouth, their distance apart being about fourteen miles; the latter station was removed, in October 1898, to the mouth of Poole Harbour, a distance of sixteen miles from the Needles. Temporary installations were also put up on board the royal yacht, for communication with Ryde, and on a tug boat off Kingstown to report the progress of the yachts during a regatta.

The experimental development of the system may be followed by reference to the records of the Patent Office and to the reports of Mr Marconi's occasional lectures to scientific societies. Early in the course of the experiments the large elevated capacity was discarded, a simple wire of from 100 to 150 feet in height being found to be sufficient.

In 1898 a radical improvement was made in this receiver which immensely increased both its sensitiveness and reliability, and rendered possible the "tuning" of pairs of stations so that interference need not occur. This essential change was brought about by the introduction of a very small transformer between the elevated wire and the coherer circuit.

Of the three advantages which are mentioned above, the reliability was increased by the provision of a direct conducting path to earth, along which any atmospheric electricity could flow gently without affecting the coherer, and the sensibility was made greater by the increased voltage in the secondary, due partly to its action as a step-up transformer, but mainly to conversion of the coherer circuit into one capable of resonance. This last result of the change was also that which made discrimination between stations possible.

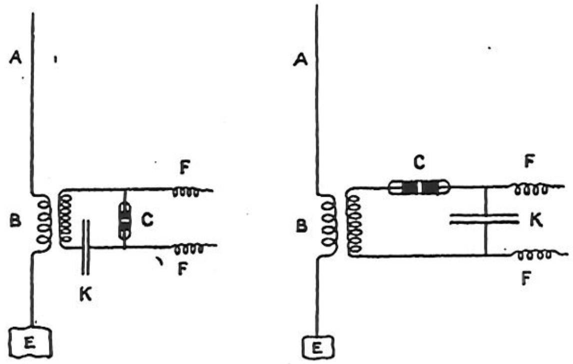


FIG. 25.—RECEIVING TRANSFORMER OR JIGGER; TWO METHODS OF CONNECTION TO THE COHERER CIRCUIT.

A, Aerial Wire; *B*, Jigger; *C*, Coherer; *E*, Earth; *K*, Small Condenser; *F*,*F*, Choking Coils leading to Battery and Relay.

Many and varied types of transformer were tried before one was found on which signals could be successfully received. Ultimately the form adopted consisted of primary

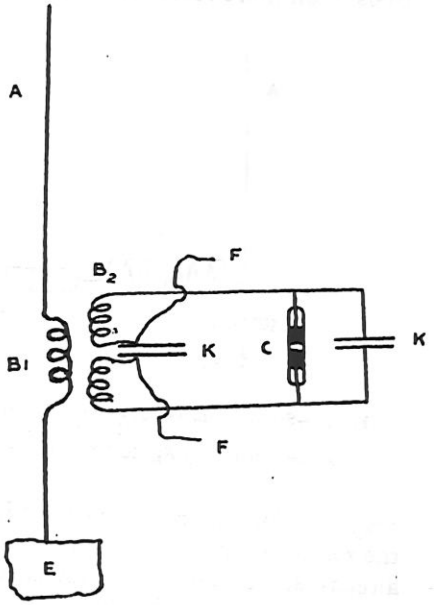


FIG. 26.—JIGGER WITH SPLIT SECONDARY.

A, Aerial Wire; B_1, B_2, Primary and Secondary of Jigger; *C*, Coherer; *K*, *K*, Condensers; *F*, *F*, Leads to Relay Circuit; *E*, Earth.

coil of about one hundred turns of fine copper wire wound on a glass tube of a few millimetres diameter, with a secondary of about two hundred turns of still finer wire wound in one layer on top of the primary. The primary was connected to the air and earth wires; one end of the secondary was connected directly to one end of the coherer, and the other, through a small condenser, to the other end of the coherer. It was found that, for reasons which will be explained in a later chapter, it was of no advantage to increase the ratio of the secondary to the primary by adding a second or third layer over the first; in fact, that such an addition usually rendered the transformer entirely inoperative. The patents taken out on this subject show that the difficulty was to some extent got over by winding the secondary on a narrow base in layers of diminishing length. The complete solution of the problem was not obtained until it was found that to get the best results there had to be a definite relation between the length of the secondary and that of the aerial wire—that, in fact, the secondary circuit acted as a resonator,

whose frequency was the same as that of the transmitted waves. We shall return to this subject in Chapter XVI.

The author made a further improvement by splitting the secondary and inserting a small condenser at its middle point; the connections to the relay circuit being made from either side of the condenser, and those to the coherer from the outer ends of the secondary. A still further development was to employ the central part of the secondary as primary, by making connections to two points on the wire separated so as to include only a few turns in the aerial circuit. This method of connection is now called "direct coupling," as opposed to inductive coupling by means of a separate primary and secondary. These transformers are shown in Fig. 27.

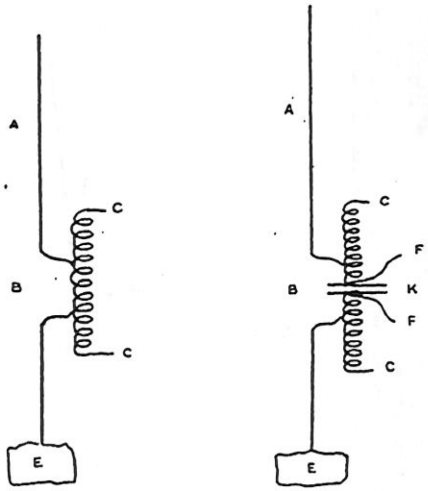


FIG. 27.—DIRECTLY COUPLED AERIAL AND RECEIVING CIRCUIT, WITH AND WITHOUT CONDENSER.

A, Aerial; *B*, Jigger; *C*, *C*, Connections to Coherer Circuit; *E*, Earth; *K*, Condenser; *F*, *F*, Leads to Relay Circuit.

In 1900 Mr Marconi improved the type of wave radiated from the transmitter by using a separate high frequency current generating circuit with the proper capacity and inductance, and having a spark-gap in it. The aerial was coupled to this primary circuit by a transformer. If, in Fig. 25, C represents a spark-gap, and F F leads from the coil, the figure will represent this transmitter.

These improvements so greatly increased the sensibility of the receiver that distances of over a hundred miles were possible with a transmitter of the same power as had previously been necessary for communication at ten or fifteen miles.

Lodge.—Sir Oliver Lodge, in 1897, took out a patent for a "syntonic" system of wireless telegraphy, based directly on his own work on the discharge of Leyden jars, and on Hertz's experimental results. The transmitter consisted of two large cones of sheet metal placed with their axes in a vertical line, and having a spark-gap between their apices. In another form of transmitter, a single metal sphere separated by small spark-gaps from the terminals of an induction coil, was used as radiator. Both types produced direct Hertzian radiation, the latter giving waves of very high frequency. The spherical oscillator was partially enclosed in a copper cylinder, open at one end, in order that the rays might be condensed in one direction. The receiver, for use in connection with the large cones, consisted of two similar cones connected through the primary of a small transformer, the secondary of which was connected to the coherer circuit. The dimensions of the transmitter and receiver were adjusted to give

no grounds

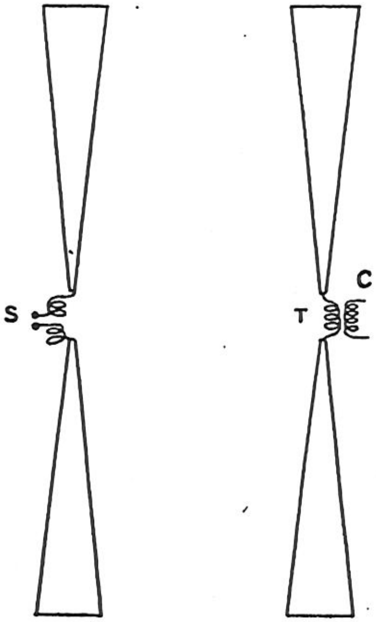


FIG. 28.—LODGE'S SYNTONIC SYSTEM, PRINCIPAL CONDUCTORS.
S, Spark-Gap; *T*, Receiving Transformer; *C*, Leads to Coherer.

equifrequent natural vibrations and therefore resonance. No earth connection was made, as it was desired that the transmission should be purely by means of free radiations. The early conical form of radiator has now given place to the horizontal conductors shown in Fig. 4. Stations in which this latter arrangement has been adopted are now working in various parts of the world.

The systems of which we have just sketched the development, may fairly be said to form the fundamental basis of all more recent work in this branch of electric telegraphy. Innumerable inventors have tackled the subject, the result being an ever-increasing crop of patents, of which already some one or two thousand have been granted in this country alone. Many of these are, of course, for trifling changes or for "improvements" long since discarded by the foremost workers in the field, but a large residue consists of devices which are or may be of real value.

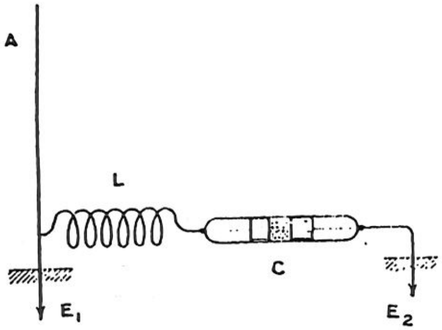


FIG. 29.—SLABY RECEIVING STATION, PRINCIPAL CONDUCTORS, DOUBLE EARTH CONNECTION.
A, Aerial Wire; E_1, E_2, Earth Connections; *L*, Inductance; *C*, Coherer.

The experimental work, for instance, of Professors Braun and Slaby, and of Count Arco, cannot be passed over without notice; particularly as its results are now embodied in the patents of the German Gesellschaft fur Drahtlose

Telegraphie, under the name of the "Telefunken" system. This company works in conjunction with the official services in Germany, and has probably a larger number of stations than any other in existence. It was reported at the annual meeting in 1905, that 518 installations had been erected.

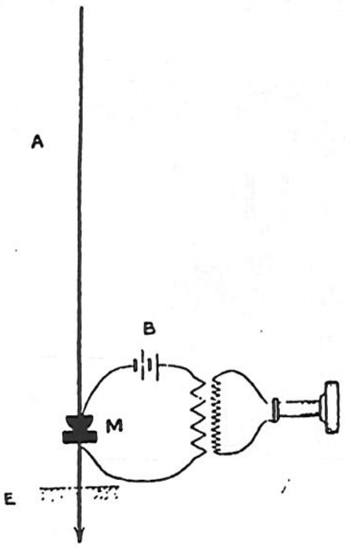


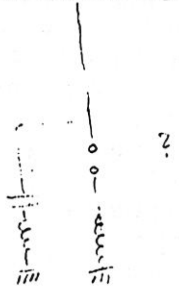
FIG. 30.—MICROPHONE AS DETECTOR IN CONJUNCTION WITH TELEPHONE.
M, Microphone; *B*, Battery; *A*, Aerial Wire; *E*, Earth.

The Slaby-Arco was apparently the first system in which an aerial wire connected to both terminals of the induction coil was used. The wire was arranged in the shape of an arch with a spark-gap at the lower end of one side. If the two sides of the arch be of equal electrical dimensions, no radiation takes place; but if the capacity or inductance of one be considerably greater than that of the other, the circuit is unsymmetrical and becomes a good radiator. It is an advantage to connect one of the terminals to earth. A somewhat similar aerial is employed by Maskelyne. This type of aerial has some advantages over a single wire, but is at the same time more troublesome to erect. It appears to be no longer in general use. Another method employed by Slaby was to use one aerial wire, but two earth connections; these were connected by a wire through the receiver. The receiver is in this case tuned by the insertion of an inductance in series with it, and only responds to waves of a certain frequency. Atmospheric disturbances do not disturb it unless they are exceedingly violent, nor do transmitters of a different frequency.[*]

For transmission, the spark-gap between the terminals of the induction coil is at the middle of the horizontal wire, one end of which is earthed through a condenser and inductance, while the other is connected to earth through an inductance only. In cases where a record of the message is not required, a combination of microphone and telephone forms a very sensitive receiver. The microphone acts, as Hughes showed, as a coherer, and the click produced in the telephone renders the signal audible. A telephone in conjunction with some type of high frequency current detector is used in most modern systems—among others by Marconi, with his magnetic detector; by Fessenden, with an electrolytic responder; and by De Forest and many more in connection with various species of coherers or microphones.

---

[*] Slaby, "Fortschritte der Funkentelegraphie," *Zeitschr. des Vereines Deutscher Ingenieure*, July 27, 1901.



CHAPTER III.

APPARATUS USED IN THE PRODUCTION OF HIGH FREQUENCY CURRENTS.

THE earlier methods of producing currents for the transmission of electrical energy over the earth's surface without the use of a return wire, *i.e.*, without any wire at all between the stations, have been sketched in Chapter II. It is now necessary to describe in some detail the types of apparatus which are employed for this purpose. It is clear that as there is no return wire the only practicable way of distributing the energy necessary to telegraphy is by means of alternating currents. Since the energy transmitted depends both on the current and voltage, it is necessary, in order to avoid the use of excessively large capacities, to obtain large currents while using small quantities of electricity by increasing the rapidity of the motion of the electricity. High frequency of alternation and comparatively high voltage are therefore employed almost universally in wireless telegraphy.

In an alternating current generator of the usual power station type the number of alternations per second is governed by the number of pole pieces and the rate of revolution. For electrical and mechanical reasons it seems impossible to increase either of these quantities indefinitely, as the losses from eddy currents and hysteresis become very great, and there is also danger of the machine flying to pieces from the high speeds necessary. Mr Tesla in 1893 obtained a current of several amperes at frequencies of from ten to thirty thousand periods per second; ten years later Mr Duddell constructed a generator which gave about

a tenth of an ampere, the frequency being 120,000 periods per second.*

The accompanying illustration (Fig. 31) shows a generator constructed by Mr Tesla in vertical cross-section, with some details. As will be seen, the machine comprises an annular magnetic frame, the interior of which is provided with a large number of pole pieces D. Owing to the very large number and small size of the poles and the spaces between them, the field coils are applied by winding

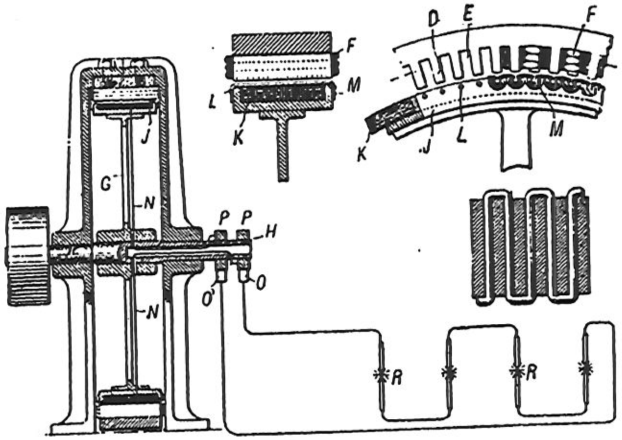


FIG. 31

an insulated conductor F zigzag through the grooves, as shown, carrying the wire around the annulus to form as many layers as is desired. In this way the pole pieces D will be energised with alternately opposite polarity around the entire ring. For the armature, Mr Tesla employs a spider carrying a ring J, turned down, except at its edges, to form a trough-like receptacle for a mass of fine annealed iron wires K, which are wound in the groove to form the core proper for the armature coils. Pins L are set in the sides of the ring J and the coils M are wound over the periphery of the armature-structure and around the pins. The coils M are connected together in series, and these terminals N carried through the hollow shaft H to contact-rings P P, from which the currents are taken off by brushes O. In this way a machine with a very large number of poles may be constructed. It is easy, for instance, to obtain in this manner three hundred and seventy-five to four hundred poles in a machine that may be safely driven at a speed of fifteen hundred or sixteen hundred revolutions per minute, which will produce ten thousand or eleven thousand alternations of current per second. Arc lamps R R are shown in the diagram as connected up in series with the machine. High frequency alternators of this type have been used by Fessenden.

---

* For list of H.F. alternators built by other experimenters see Ernst Ruhmer's "Wireless Telephony" (Crosby Lockwood, London).

Goldschmidt's High Frequency Dynamo.—The great difficulty, indeed practical impossibility, of constructing a satisfactory dynamo on the principle of those just described, led Dr R. Goldschmidt a few years ago to study the problem with the view of discovering a design which would make an efficient high frequency machine a possibility. In this he has been successful, at least in so far as machines suitable for long-distance transmission are concerned, and at the present time (August 1912), machines to give 150 K.W. at 50,000~ are nearing completion. As these are based on the very satisfactory performances of smaller machines of the same type, there is every prospect that they will fulfil their designer's intentions.

The Goldschmidt machine attains its high frequency by the addition of rotating magnetic fields to actual mechanical rotation. The mechanical difficulties due to the tendency of a fly wheel to burst at excessive speeds, and the consequent necessity for the employment of a very small pole pitch which were unavoidable in earlier forms of high frequency alternators are thus avoided. A much lower speed and a much greater electrical efficiency are therefore obtainable than in the Tesla and similar machines.

In practice the machine consists of a rotor and stator, both wound in simple "wave" windings to give 15,000 ~ at the normal speed of revolution, this being the highest frequency for which an efficient machine of ordinary design can be built. The circuits, electric or magnetic, are so arranged that the 15,000 ~ current in the rotor is returned to the stator in which it produces a magnetic field rotating in the opposite direction to the mechanical rotation of the rotor. The stator has thus a new current of frequency, 30,000, induced in it, which in turn is sent back to the rotor, giving a frequency of 45,000. Higher frequencies may be obtained by a repetition of the process. At 60,000 ~, corresponding to a wave-length of 5,000 meters, the electrical efficiency of the machine is remarkably high, being comparable with that of an ordinary alternator. In Fig. 32 a diagram of the machine shows the method by which the lower frequency currents are given closed oscillating paths in which to circulate freely in order that the final high frequency current may be produced. The energy is conveyed between rotor and stator by electro-magnetic induction, hence conducting connections are not required. The stator may be excited either by direct or by alternating current. With the former a uniform h.f. current is produced, while with the latter the variation corresponding to the frequency of the exciter is superposed. A fine musical note is heard at the receiving station if the frequency of

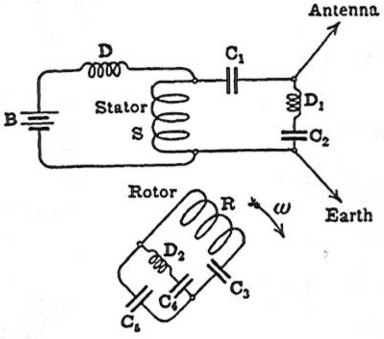


Fig. 32.—Goldschmidt's High Frequency Dynamo.

B, Battery for direct current excitation; C_1, &c., Condensers; *D*, Choking Coil; D_1 D_2, Inductances.

the exciter be suitable. By putting a microphone in the direct current excitation circuit, speech is transmitted with excellent articulation. This result shows the remarkable perfection to which the design and construction of the machine has been carried. It means, for instance, that in a test made by the author, a pair of ordinary microphones in series were able to control exactly and produce large variations in the output of a machine giving 3 or 4 K.W. of high frequency power. This result is no doubt due to some extent to the fact that the machine is in reality largely self-exciting, the primary exciting power being only a small percentage of that required in an ordinary machine, but it also proves that the construction of the machine is such that wireless telephony, on a scale hitherto impossible, is easily practicable, and that no serious difficulties need be anticipated in the attainment of very high speed telegraphic transmission. Further details are given in a later chapter.

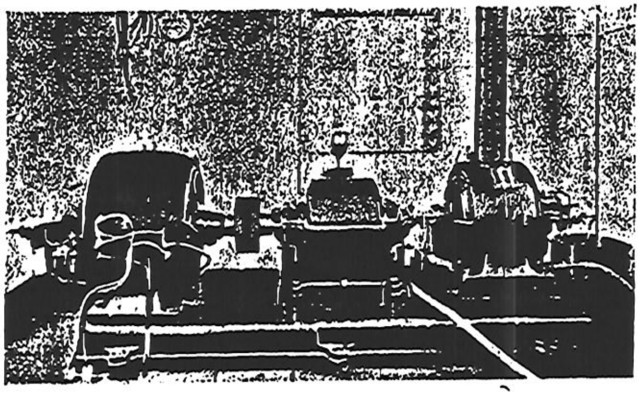


FIG. 33.—GOLDSCHMIDT'S ALTERNATOR.

On left the Motor; in centre the Gear; on right the Alternator. In more recent patterns the Gear is omitted. This figure represents the first machine constructed.

Static Frequency Converters.—Goldschmidt, and almost simultaneously Vallauri in Italy, and Joly in France, have invented types of frequency transformers which depend on the difference in phase between the alternating currents passing through two branch circuits, in one of which the lag due to hysteresis of an iron core is greater than in the other. The efficiency of such a converter appears to be essentially low, but the apparatus may be of use in obtaining higher frequencies than are given by the dynamo in cases where electrical efficiency is not of great importance.

Generation of Uniform High Frequency Currents by Introduction of a Gaseous Section in a Direct Current Circuit.—Since the publication of the first edition of this handbook, a considerable number of methods have been invented or further developed for the production of uniform alternating currents of high frequency by the use of what up till now has usually been called an "arc." This term, however, does not accurately describe the electrical process, nor does it discriminate between the many types of discharge intermediate between a continuous current and an intermittent series of oscillatory spark discharges, which are employed by one or other of the inventors in their apparatus.

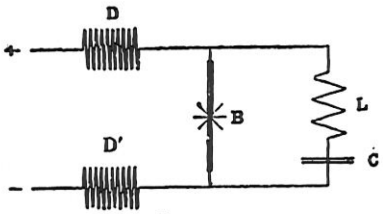


FIG. 34.

B, Gaseous section; *L*, Inductance; *C*, Capacity; *D*, Chokers.

We may class these types roughly as follows, first premising that the source of energy is in every case a direct current supply at some steady voltage: (1) A uniform sine wave alternating current, produced by a direct current through air, the gap being shunted by a circuit containing sufficient capacity and inductance to give it a natural free period of oscillation (Duddell). (2) The same through hydrogen gas, giving more energy to the alternating current and a higher frequency (Tesla, Poulsen). In these cases the direct current component is always greater than the alternating component, hence the current through the gas never falls to zero and is never reversed in direction—it merely varies in strength. (3) Unidirectional dead-beat discharges occurring at a high frequency; obtained when a magnetic, or air blast acts on the gaseous section in the circuit described above (Thomson, Fessenden,* Poulsen, Galletti). In this case the current in the gap is zero during a period which may be merely momentary, or may amount to several times the natural period of oscillation of the circuit, *i.e.*, the oscillations are "forced." (4) The case in which the current not merely falls to zero, but is actually reversed, although the wave is not of sine form and the period between two positive maxima is not the natural period of the circuit. This is an inefficient type of current which is avoided in practice, since it does not cause the receiving circuit to resonate, the positive and negative waves being of unequal duration.

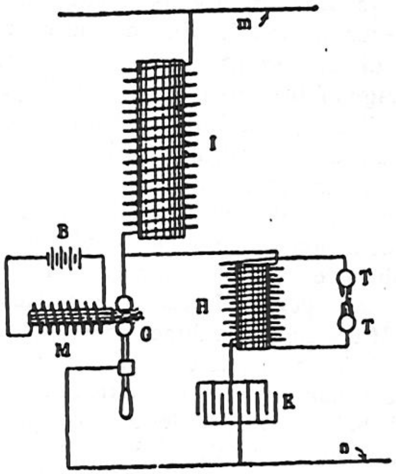


FIG. 35.—ELIHU THOMSON GENERATOR. Main Circuit, *m I G n*; Shunt, *K*, *H*; Magnetic Field, *M*, *B*; D.C. Supply, *m* and *n*.

This passes into the next form by lengthening of the intervals between positive maxima until the reverse current entirely dies out in the interval. And (5) the discharge takes the form of a series of sparks following one another with great rapidity at a rate which has no relation to the natural frequency of the oscillatory circuit, though the actual damped oscillations in each spark have the natural frequency of the circuit. We have thus progressed from uniform alternating current, oscillating freely at the natural period of its circuit, through various types of forced oscillations to an intermittent series of discharges each of which oscillates with the natural period of the circuit. The first type is properly called the "Arc" and the last the "Spark." In addition to the above type of high frequency current generator, in which a single shunt circuit containing capacity is employed, others exist in which the oscillating circuit is more complicated. There are, for instance, (6) Marconi's double reciprocating circuit with two gaseous sections (see Chapter VIII.), which appears to produce a uniform high frequency current, and (7) von Lepel's generator in which one gaseous section is associated with a compound circuit. The types of oscillation produced by these last two are described in Chapters VIII. and XIII. In (6) the current is nearly uniformly alternating, and in (7) consists of a very rapid succession of very slightly damped wave trains.

Conduction through a Gas.—The properties of a gas in regard to the conduction of electricity are in many respects totally unlike those of a metallic conductor.

In the first place, most gases at atmospheric temperatures and pressures are almost perfect insulators. If, however, the temperature be sufficiently raised, or the pressure reduced, ionisation, *i.e.*, splitting of the molecules, takes place, and the gas becomes a conductor. The same result is obtained by raising the voltage between two solid electrodes in the gas until a disruptive discharge commences.

---

* Fessenden uses a high resistance "whereby any desired number of discharges per second across the spark-gap may be produced"; *i.e.*, forced vibrations.

Characteristic Current-Voltage Curve of the Arc.—Now, since an electric current through a gas raises its temperature, the conductance will be maintained, and in general the greater the current the greater will be the conductance of the column of gas between the electrodes which carries it. If this increase of conductivity were simply proportional to the current, the voltage required on a gaseous section of the circuit would be the same whatever the current flowing. Since, however, the heating effect increases more rapidly than in simple proportion to the current, the actual result is that the greater the current the less is the voltage taken up by this section, until a point is reached at which cooling by radiation and convection check the rapid increase of conductance, and the conditions become stable. The value to which the voltage drops before this condition is attained is different for different electrodes and for different gases. In direct current arc-lighting the current is usually in this stable condition.

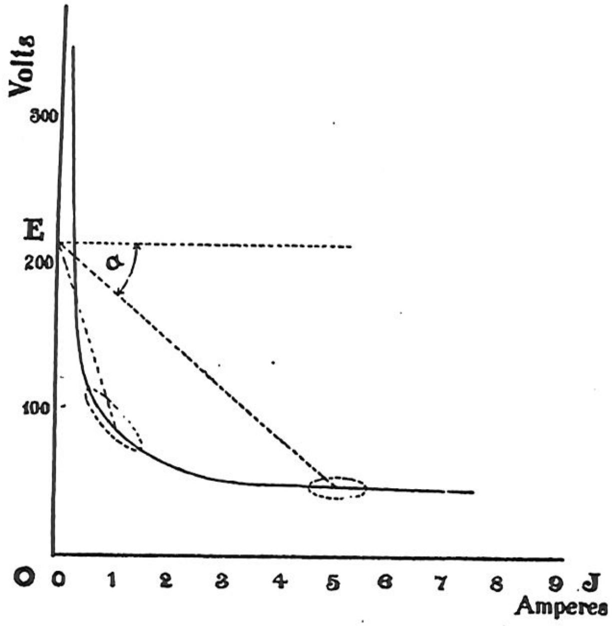


FIG. 36.—H. AYRTON'S ARC CHARACTERISTIC.

The dotted closed curves correspond to cyclic variations. The horizontal dotted line is at voltage of supply. The tangent of *α* is proportional to the resistance in series with arc for given cyclic curve.

The Unstable Arc as Generator of H.F. Current.—If a condenser, *i.e.*, some contrivance which will hold a charge of electricity, is connected in parallel with the gaseous section, it will become charged to the voltage of the direct current supply. When the arc is struck the voltage of the gaseous section drops, hence the condenser will discharge itself through this section, increasing its conductance and causing a still more rapid drop of voltage. When the stored electricity is exhausted the current will decrease, and, owing to the increase of resistance consequent upon the cooling of the gas, the voltage will again rise. The condenser will again become charged, and the cycle will recommence (see Fig. 40).

If the electrical dimensions of the shunt circuit are such that it is not capable of free electrical vibration, *i.e.*, if 4L is less than R^2C, the oscillations will be forced in character, and their period will depend mainly on the product R^2C *; while if it is capable of free vibration, *i.e.*, if 4L is greater than R^2C, its natural oscillation frequency will in the main control the movement of electricity and the amplitude of the resulting oscillation will be larger. In general, therefore, the frequency of oscillation in such a circuit is not the same as it would be were the circuit metallic, and cannot be calculated, even approximately, from the capacity and inductance alone. There are variable factors, such as the rates of cooling of the gas and electrodes, which are absent in a metallic circuit but which seriously influence the rate at which the voltage falls and rises in the alternate charge and discharge of the condenser.

---

* P. 240; also M. La Rosa, *Accad. Lincei*, Atti 16, 20th Jan. 1907.

The whole action is in fact comparable with that of the bow on a violin string, where a steady direct motion also causes a vibration. On the violin it is all too easy to produce with the bow tones (squeaks) far different from the free vibration of the string, which would be obtained if the string were plucked with the fingers and left to itself to vibrate. In like manner the frequency of oscillation of electricity in a condenser circuit, a portion of which is gaseous, connected to a steady source of current, is by no means necessarily the same as the free frequency of the circuit.

It has been found by experiment that every alteration in the length of the gaseous section is accompanied by an alteration in frequency. Hence the necessity for maintaining the gaseous section constant in all respects, a difficult problem for which many solutions have been proposed. The usual method is either to move the electrodes so that the discharge between them starts continually from a new surface, or to cause the discharge to travel from point to point of the surface, and thus attain the same result (Poulsen, Ruhmer, and others). The end obtained is uniformity in the condition of the gaseous section, and, if the motion be sufficiently rapid, an increase in the rate of change of voltage during each oscillation on account of the fact that the discharge is being continually forced forward into a region of cool and non-ionised gas (Marconi). To obtain the latter effect an air blast or a powerful transverse magnetic field has also been used (Elihu Thomson, Poulsen, and others), which drives away the ionised gas from the electrodes. Hydrogen, or a hydrogen compound, also increases the frequency and energy of the oscillation. The reason for this is not quite clear, but its high conductivity for heat has been suggested as an explanation, and in

addition there is undoubtedly the secondary advantage that since there is no combustion the electrodes remain in a much more constant condition than they would in air.

Types of Discharges obtained by Application of a Steady Voltage to the Gaseous Section of a Condenser Circuit.—Two types of uniform oscillation, which may occur under different conditions in the gaseous section of a circuit, are shown in Figs. 38 and 37. The first is that of the Duddell musical arc, in which the variation of the arc current takes the form of a sine wave superposed on the direct current. The latter, however, is always greater than the oscillating component, hence the actual current in the arc never becomes zero nor suffers reversal.

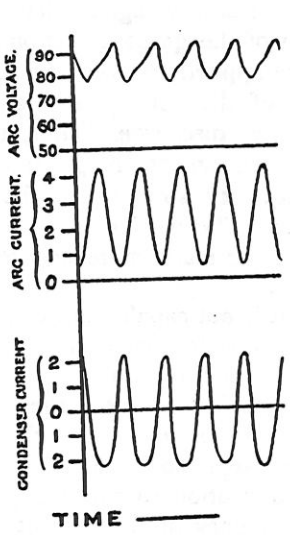


Fig. 37.—Sine Currents (in Amperes).

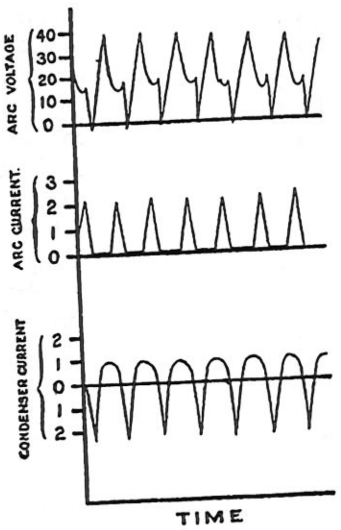


Fig. 38.—Dead Beat Currents (in Amperes).

The second figure shows a series of impulsive discharges, not free spark discharges since they are non-oscillatory, and at the same time unlike the previous type since the alternating component has no resemblance to a sine wave, or indeed to any ordinary type of wave, for it consists of a series of short discharges of large amplitude in one direction separated by longer periods during which the current is zero. The length of the zero period depends not only on the capacity and inductance of the oscillatory circuit, but on the resistance and voltage in the supply circuit, and on the conditions of the gaseous section. Thus, for instance, increase in the applied transverse magnetic field increases the duration of the zero period and thus changes the character of the discharge. Thus, though this type of discharge results from the charge and discharge of a condenser, its frequency is not that of the circuit considered as a free vibrator. The motion is, in fact, a forced one, and is capable of being made more energetic than that of the simpler, sine wave type. Though more energetic, this form of current is not capable of exciting resonance to the same degree as the sine wave type.

There is still a third type which is practically a very rapid succession of spark discharges. Here the discharge is no longer uniform but is a series of rapidly damped oscillatory discharges following one another at intervals which have no relation to the free period of the circuit, though the frequency of the current in each discharge is that of the circuit.

The Duddell, Tesla, and Poulsen arcs, with no applied magnetic field or only a very weak one, generate the first type of current. Marconi's double-circuit rotating discs the first or second; the Ruhmer arc-interrupter, and Poulsen arc with transverse field, the second; the Elihu Thomson generator the second or third, and Fessenden's improvement on the last-mentioned any one of the three, according to the conditions prevailing in its circuit.

Characteristic Curves of Uniform High Frequency Currents.—The most satisfactory way of studying the various types of current produced by high frequency current generators of any kind is by examination of their characteristic curves obtained by means of an oscillograph of the cathode ray (Braun's) form, in which the vertical and horizontal co-ordinates are proportional respectively to the voltage and current through the gaseous section. A curve thus obtained is a true energy characteristic like a steam engine indicator diagram, and shows the actual work done per cycle (see p. 64).

The curves shown in Fig. 40 are drawn from photographic records made by means of a cathode ray oscillograph.

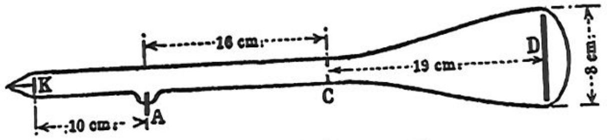


FIG. 39.—BRAUN'S OSCILLOGRAPH.

K, Cathode; *A*, Anode; *D*, Fluorescent Screen. (See also Figs. 41, 42.)

Braun's Cathode Ray Oscillograph.—This instrument consists of a glass tube containing gas at a very low pressure. It is provided with electrodes, from one of which the cathode rays of a faint greenish colour stream out when a high voltage is applied, from a Wimshurst machine for instance. A metal plate with a small hole in it is placed across the tube so that only a small pencil of the rays passes into the further part of the tube. This ray consists of moving charged molecules of the gas, and so constitutes a convection current of electricity. The ray is thus deflected by a magnetic or an electric field, the amount of the deflection showing the strength of the field. Also, since the mass of the ray is infinitesimal, the deflection can follow the most rapid variations of the field.

At the end of the tube is placed a fluorescent screen on which the ray produces a bright spot of light. On two sides of the tube, with their planes at right angles to one another, are put two small coils of a few turns of wire;—or two pairs of plates if electric force be used. Through one of these flows the main current, and through the other a current which is proportional to the voltage in the circuit investigated.

Thus the spot will rest at some point on the screen for any given pair of values of the current and voltage, and consequently, as these vary, the spots will describe a curve. For any alternating current the curve will be a closed one, since each alternation is a complete cycle, ending where it began. Hence, at each cycle of a uniform current the spot will travel round the same curve, and if the frequency is sufficiently high, the curve will appear steadily on the screen. It can therefore be photographed or drawn without difficulty. The instrument may also be used as either a volt or ampere meter for high frequency currents, since if only one of the coils be excited, the spot will travel to and fro in a straight line, the length of which is proportional to the amplitude of the current in the coil, and thus to that of the current or voltage in the main circuit.

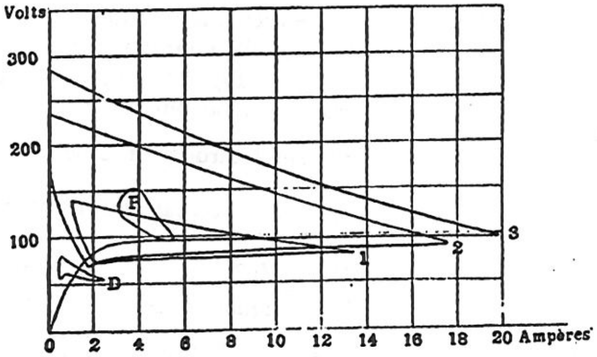


FIG. 40.

Characteristic Curves of, *D*, Duddell Arc; *P*, Poulsen Arc; *1*, *2*, *3*, Arc in strong Magnetic Field (Ruhmer). [From Ruhmer's "Wireless Telephony."]

Various Types of Characteristic Curves.—The curves shown in Fig. 40 are from photographic records taken by Mr Ruhmer. They show the enormous increase of energy per cycle obtainable by the use of a powerful magnetic field across the gaseous section. It should be noted, however, that in an actual comparison of the output of energy from each generator, the frequency of alternation must be taken into account as well as the area of the diagram. Thus the outputs will only be proportional to the areas of the curves if the frequencies are all the same.

The Poulsen curve is taken without a magnetic field. In recent Poulsen apparatus, however, a very powerful field is used. The characteristic curve in this case will therefore, no doubt, approximate to that of Ruhmer's interrupter, and the discharge will be altered from the sine wave type of the Duddell circuit, to the deadbeat impulse type of the arc interrupter. That such is actually the case has been shown by recent experimental measurements. It has been found, for instance, that under these conditions it is not uncommon for an arc circuit to give off not only its fundamental vibration, but also four or five others of higher frequencies. This is a complication even more difficult to deal with than the double (beat) frequency of spark circuits (see p. 256), since the secondary vibrations are so different in frequency to the fundamental. Thus, though tuning to any one of them may be sharp, the existence of the others causes interference at neighbouring stations whose proper wave-lengths are much less than that of the fundamental of the arc station. Perfect freedom from interference has therefore not been obtained where arcs of this type are used.

Determination of Characteristic Curves.—Dr Barkhausen, in a most interesting monograph on the "Production of Vibrations," shows how Braun's oscillograph provides a convenient method of measuring the actual energy output of a high frequency current generator. If, for instance, A be an arc or other variable resistance, and C a capacity in the alternating circuit (Fig. 41), the curve described by the spot on the fluorescent screen of the Braun's oscillograph with the connections shown will represent the relation of e, the alternating component of the voltage across the gaseous section, to E, the voltage on the condenser in the alternating current circuit. But the energy output per period is $W=\int_0^T e.dq$, where q is the quantity of charge in the condenser. Now $E=\frac{q}{C}$, where C is the capacity of the condenser; hence $W=\int_0^T e.dq = C\int_0^T e.dE$, since C is a constant. Hence the energy output per period is C times the area of the curve $e=f(E)$ described by the spot of light on the screen. A large inductance (choking coil) is placed in parallel with the condenser to permit the passage of the direct current generally used as supply to the arc. In any such measurement, it is of course necessary first to standardise the oscillograph by determining the values of its deflections by applying steady voltages in the two rectangular directions of the axes of co-ordinates.

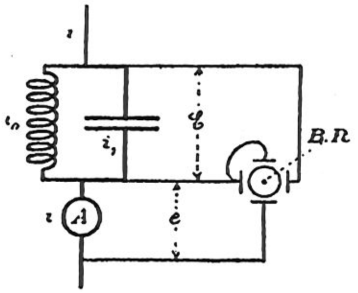


FIG. 41.—CONDENSER METHOD OF DETERMINING CHARACTERISTIC (ENERGY) CURVE AND WATTS PER PERIOD, BY BRAUN'S OSCILLOGRAPH (B.R.). [BARKHAUSEN.]

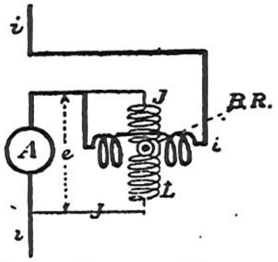


FIG. 42.—INDUCTANCE METHOD OF DETERMINING CHARACTERISTIC (ENERGY) CURVE AND WATTS PER PERIOD, BY BRAUN'S OSCILLOGRAPH (B.R.). [BARKHAUSEN.]

Note.—The capacity and inductance of the oscillating circuit are not shown.

There is a second, and generally more convenient, method of determining the energy output. In that just described, it is usually necessary to have the capacity C in addition to the other capacity in the oscillating circuit, since otherwise the inductance of the latter would form a short circuit to the direct current. A similar integral, *i.e.*, curve area, may be found in which L takes the place of C by the following method.

If in Fig. 42 a coil of large inductance, but moderate resistance, be put in parallel with the variable part A, the current I through it is determined by the equation $e=L\frac{dI}{dt}$, hence the alternating current energy per period, $W=\int_0^T i_1 e\,dt = L\int_0^T i_1\,dI$, i_1 being the alternating component. But since I has equal values at the beginning and end of a period this is equal to $W=L\int_0^T i\,dI$, where i is total current passing through the series coils of the oscillograph.

Hence if the curve giving the relation of i in the variable section to I in the large inductance be obtained (by the oscillograph) its area is $\int_0^T i\,dI = W/L$; hence L times the area is the work done per period. The total rate of working, with a uniform current, *i.e.*, the watts, may therefore be found if required by multiplying this work per period by the number of periods per second, *i.e.*, by the frequency.

Spark Discharges.—The fact that if a condenser be discharged through a circuit of low resistance the current is not continuous but oscillates to and fro a number of times before dying out, has also been made use of. To obtain the high voltage necessary to charge the condenser, two methods are available. The first is to use an electrostatic machine; but on account of the small output of even a large machine, this method has not been used in practical telegraphy. The second method consists in transforming a current of low voltage into one of very high voltage by means of some type of induction coil or transformer. In

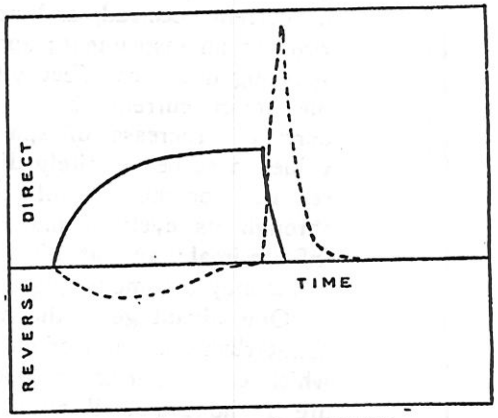


Fig. 43.—Action of an Induction Coil.

Horizontal Distance represents Time. Vertical Distance, Current or Voltage. The full line represents Current in Primary, and the broken line the Voltage induced in Secondary.

the induction coil an intermittent unidirectional current in the primary coil induces an alternating current of high voltage in the secondary. On making the primary circuit the current in it increases comparatively slowly, inducing a reverse current in the secondary of low voltage, since this depends directly on the rate of change of current in the primary. On breaking the circuit the primary current ceases almost instantaneously, thus inducing a momentary current of high voltage in the secondary. It is this current which in the simpler systems of wireless telegraphy is used

to charge the aerial wire up to the voltage at which the electricity sparks across the gap to the earth wire. A frequency of one or two thousand interruptions per second is the maximum which has been as yet attained, hence the current in the aerial consists of short trains of oscillations of very high frequency following one another at comparatively long intervals, *i.e.*, each train of waves may occupy $\frac{1}{100000}$ of a second, while the interval before the next commences may be $\frac{1}{1000}$ of a second, thus the blanks may be a hundred times as long as the active periods.

Many improvements have been made during the past few years in the construction of the induction coil, the most important being due to the recognition of the fact, which Tesla pointed out in 1893, that the best results can only be obtained if the natural periods of oscillation of the primary and secondary circuits have some simple relation to one another. To attain this end it may be constructed so that the electrical dimensions of the two circuits should be such as to give the same frequency of vibration. This can be done by properly adjusting the capacity and inductance of the circuits so that the square roots of the products of these quantities for each circuit are equal.

Resonance Induction Coils.—This improvement has been carried out in a considerable number of coils now on the market. The result is a great increase in efficiency owing to the much smaller quantity of wire required in the secondary in order to attain any desired voltage.

The secondary of the transformer which supplies power to a tuned transmitter such as is indicated on p. 43, is in series with the capacity and inductance of the high frequency circuit. It is possible, therefore, by adjusting the size of the secondary, to tune this circuit to the frequency of the alternator which supplies the primary. Let N be the frequency of supply, L_p the inductance of the primary, τ the ratio of the number of turns in secondary to those in primary, and C the capacity in the h.f. (and secondary) circuit;—then, for resonance between supply and secondary circuits, $\tau = 1/(4\pi^2 L_p C N^2)$ approximately. Owing to the reaction of secondary on the primary however, τ may be 30 per cent. greater than this value. Thus the proper winding for the secondary can be determined. Under these conditions the voltage in the secondary circuit rises much higher than would be the case without resonance and a longer spark is possible, giving more energy in the h.f. circuit, and, therefore, greater radiation from the aerial. High voltages have been obtained by Mr W. H. Wilson (*Proc. Roy. Soc.* A. 87, 1912) without using resonance by employing a comparatively high frequency current in the primary. He has in consequence greatly reduced the size of the coil necessary to obtain voltages sufficient for X-ray and wireless purposes. Mr Coursey has also constructed a transformer in which a similar principle is employed.

Rate of Sparking.—It is fallacious to suppose that a very high rate of sparking, such as that given by the Wehnelt break, is necessary for rapid telegraphic work. For speeds much higher than those generally attained in wireless telegraphy, interruptions at the rate of about 100 per second, as given by the hammer break, are quite sufficient. Thirty words a minute, which is considered rapid on any system of telegraphy when the sending is done by hand, means the letter V repeated 150 times in one minute. Now V, on the Morse code, is represented by three dots and one dash. In order to transmit this letter correctly, only about ten sparks, or rather vibrations of the hammer, are required; one for each dot, three or four for the dash, four more which might have occurred during the blank spaces had the letter been a different one. Now 150 Vs per minute is 2.5 per second, hence we require 25 sparks per second. So with 100 sparks per second, as may be given by the hammer break, we have four times as many as are necessary; a factor of safety of four. As a matter of fact, the author has received correctly Vs sent at the rate of 60 words—*i.e.*, 300 Vs—per minute by an automatic key in series with an ordinary hammer break. It is essential to good transmission that every spark should be a good one, but the number is of less consequence. The reason for this is, that almost all detectors depend for their action on the maximum voltage or current received, and not on the integral current as read on an instrument; and the increase of frequency of sparking does not affect either the maximum voltage or maximum current, but merely increases the integral current. Increase of sparking rate, beyond a certain value, must be definitely disadvantageous, since the time required for the core of the coil or transformer to go through its cycle of magnetic changes is by no means infinitesimal; and at high frequencies the eddy current losses may become very great.

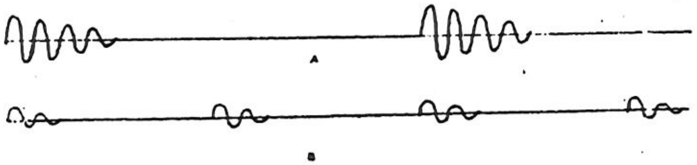


FIG. 44.—TYPES OF WAVES RADIATED.

A, Wave trains of considerable amplitude; *B*, Wave trains of less amplitude occurring more frequently. (*N.B.*—The actual intervals between wave trains are usually much longer in comparison to the length of the train than those shown.)

One advantage of the hammer break, which certainly counterbalances some of its disadvantages, is the ease with which two important adjustments may be made. These are (1) the rate of vibration, and, which is more important, (2) the duration of the contact. By the mere turn of a screw, the length of time during which the current is flowing in the primary, and therefore the maximum magnetic induction in the core, can be regulated to suit the load. The chief disadvantage is the rapidity with which the contacts wear when heavy currents are used, and the fact that it is impossible to use more than about 25 volts without producing arcing.

Mercury breaks are of two types; in the older form mercury in a small dish is connected to one electrode, while the other is attached to a plunger which dips into the mercury and is periodically withdrawn by a reciprocating mechanism. This form is practically obsolete. In more modern breaks, one electrode is a jet of mercury driven by impulses occurring with as low a frequency as a few thousands per second. Thus a thermo-electric junction, heated by the intermittent received currents, keeps on increasing in temperature for an appreciable fraction of a second. It is therefore possible to add up the effects of a succession of sparks, if these occur with sufficient rapidity. Methods have therefore been invented for the production of a very rapid series of spark discharges, by Sahulka and others. A simple method of attaining this is that described in Webb's British patent, No. 7,687 of 1907. A high ratio transformer in series with a rectifying valve is used to keep a very large condenser charged to a high voltage. The condenser forms a reservoir from which leads, of very high resistance, supply current to a small spark-gap in an oscillating circuit. By regulation of the resistances it is found possible to maintain a very rapid series of spark discharges at the gap. Each spark is oscillatory as when an induction coil is used, but the spark rate is raised to over 4,000 per second, thus allowing the thermo-detector at the receiver to integrate the heating effects of a number of sparks.

Circuits used in Transmitters.—In systems using a uniform high frequency current, whether this be produced by a dynamo machine or by an arc, the generator is usually placed directly in series with the aerial and earth conductors.

In shock-excited spark systems a much damped primary is coupled to the antenna, the latter only containing current suitable for transmission.

In the earlier types of spark system, *e.g.* Marconi, the main generating circuit is distinct from the radiating circuit and is coupled to it by magnetic induction or otherwise. In this case the primary and aerial currents are of the same type.

CHAPTER IV.

DETECTION OF SHORT-LIVED CURRENTS OF HIGH FREQUENCY BY MEANS OF IMPERFECT ELECTRICAL CONTACTS.

IN order to detect the existence of oscillatory currents in the circle of wire which he used as a resonator, Hertz made a small break in the continuity of the conductor and observed the sparking which took place there. This method is obviously not a very sensitive one, as a considerable voltage must exist across the gap before a spark will pass, even if the gap be very small.* No practical system of telegraphy could therefore be based on the use of so insensitive a detector.

Ordinary telegraphic instruments are totally inapplicable to the detection of high frequency currents, since even the most sensitive requires that a unidirectional current should pass through it for about $\frac{1}{500}$ of a second before it will act. The currents employed in spark telegraphy are, however, oscillatory, and last perhaps, $\frac{1}{100000}$ of a second; to detect them it is thus necessary to use an instrument which will be actuated by a current lasting only the 200th part of the time required by an instrument suited to wire telegraphy. And again, the fact that the currents are oscillatory prevents the employment of the electro-magnets which are so general in apparatus for wire telegraphy. Even the telephone is unsuitable because of its inductance and also on account of the inability of the ear to detect tones of very high frequency.

---

* See Tables, Chapter XXI.

For spark telegraphy, therefore, not only was a new type of transmitter requisite, but also an entirely new method of detecting the transmitted currents and so receiving the signals.

The first practical detector of oscillatory currents of high frequency was the loose contact between conductors named by Hughes the microphone, and shown by him to have the power of detecting both mechanical and electrical vibrations. If the loose contact be between two pieces of carbon, the change in resistance is only momentary, the effect is therefore not detectable on a galvanometer, but is easily observed by means of a telephone since the latter is so much more rapid in action. With metallic contacts a permanent change of resistance takes place which may be indicated by a galvanometer or any type of telegraph instrument in circuit with the loose contact and a local battery. The contact does not, however, restore itself to its original state of sensibility automatically but remains cohered, or welded, until the pieces of metal are separated by mechanical force. The actual force which must be applied in order to separate two pieces of metal which have been electrically cohered has been measured by Dr P. E. Shaw.*

Coherers consisting of only two conductors in loose contact have the disadvantage of being very easily disturbed by mechanical vibration, and are thus unreliable and of little use for telegraphic purposes. The carbon microphone has, however, been used by Braun and others with considerable success as a detector.

The sensitiveness of the loose contact to the action of electric currents was rediscovered by Calzecchi-Onesti, Lodge, and Branly. The last named employed the form which has been developed into the coherer of practical telegraphy. Branly's tube had an electrode at each end, and

---

* *Phil. Mag.* March 1901 and August 1904.

was filled with a quantity of fine metal filings. The uncertainty of a single point contact was thus obviated and the disturbing effects of mechanical vibrations were minimised. In its original form its action was somewhat erratic at times; Marconi has, however, developed from it an instrument which, when properly treated, is as reliable in its action as any other telegraphic apparatus. Early experimenters spoke of the coherer as delicate and unreliable—a criticism which was in reality a confession of ignorance of its proper construction and conditions of use, and though for most purposes it has been superseded by more sensitive detectors, it is still in use at a few stations of the various companies. Mr Marconi reduced the size of the tube until the space containing the filings was merely a small disc-shaped cavity less than a millimetre long and about five millimetres in diameter between two silver plugs. The filings filled only about one-third of the cavity and consisted chiefly of nickel, a trace of silver being added to increase the sensibility, and the tube contains a partial vacuum.

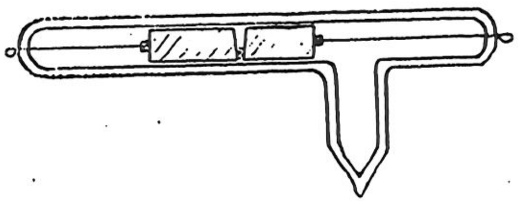


FIG. 45.—MARCONI'S FORM OF COHERER.

At the author's suggestion the filings were sifted through pieces of fine silk gauze to obtain uniformity in size. This construction was of course only arrived at after many experiments with tubes of other dimensions and containing filings of many other metals. The advantage of the coherer for wireless telegraphy is that it remains cohered until the filings are shaken up again. The momentary oscillatory current thus records itself in a permanent reduction of the resistance of the coherer, which continues so long as the tube is not shaken. The introduction of the coherer in the path of the oscillatory currents therefore provides a means by which any ordinary telegraphic instrument can be actuated, and will respond only on the arrival of oscillations at the coherer. The coherence lasts while the current from the local battery flows through the circuit and causes the telegraph instrument to indicate its presence. If the effect on the coherer had been merely transient instead of semi-permanent, it would not have been possible to use a recording telegraph instrument, or indeed any kind of apparatus whose action is controlled by electro-magnets.

Since the coherer does not return to its original sensitive state automatically, it is necessary to arrange that it should be shaken immediately after a signal has been recorded. This of course involves the use of a mechanism which acts in conjunction with the recording instrument and administers a tap to the tube sufficient to decohere the filings. The complete receiver is thus somewhat more complicated than if a self-restoring detector were used, but it has the advantage that it is capable of producing a permanent record, on a Morse tape, of the signals received. Where a self-restoring detector is used the signals must as a rule be read by the sounds they produce in a telephone receiver.

Though many variations have been proposed by various experimenters, the utility of the type of filings coherer designed by Mr Marconi, is proved by its continued use at the stations of many companies in Europe and America. The mode of action of the filings coherer has been the subject of much discussion. Many of the earlier experimenters appear to have fallen into the curious logical fallacy of supposing that because electric waves caused coherence they were therefore essential. The fact is that the only necessary condition is that a certain voltage be applied to the tube of filings; whether it be oscillatory or continuous is probably a matter of indifference. If a slowly but continuously increasing voltage be applied to the terminals of a coherer, its resistance will diminish just as rapidly, when a certain point has been reached, as if electric waves had arrived. After all, electric waves are merely rapid changes of potential, and it is not the rapidity which causes coherence but the difference of potential. At my suggestion Dr W. H. Eccles made a very thorough experimental investigation of the subject, and found (as I had always supposed) that oscillations have nothing to do with the matter, *i.e.*, that they are by no means essential to coherence. His results are so important both from the theoretical and practical points of view, that I shall later on quote somewhat fully from his paper.

In Faraday's well-known method of showing the lines of force of a magnet, small particles of iron form chains when placed in a magnetic field. If they are lying on a comparatively rough surface, such as paper, gentle tapping, which lifts them momentarily into the air and thus allows them to set themselves freely along the line of force, facilitates the action. Robertson has shown that small conducting particles, such as sawdust, behave in an exactly similar manner under the influence of electrostatic force. Their ends become charged, and as the ends of neighbouring particles, in the direction of the force, are oppositely charged, they attract one another and form conducting chains. The final result is a greater conductivity in the whole mass. It is important to note, from a practical point of view, that intermittent mechanical shocks facilitate the formation of chains, just as in Faraday's experiment. This explains the well-known influence of the adjustment of the tapper in a wireless telegraph receiver.

I have noticed that if the voltage in the local circuit of a coherer be increased to a certain point by means of a potentiometer arrangement, the sensitiveness of the apparatus is much increased. If the steady potential applied be nearly large enough to cause coherence, the slightest rise, due to the waves, determines the result.

With this preliminary I shall now quote some sections from Dr Eccles' paper.*

"*Preliminary.*

"The investigation described in the following pages† was commenced early in 1900 with the object of revising what was then known of the relative influences of oscillatory and of steady P.D.s in promoting coherence in filings coherers. It was hoped that evidence might be obtained which would decide definitely whether the action of electrical vibrations was in character different from or similar to that of steady E.M.F.s. The importance—from several points of view—of this discrimination is manifest; and that the difference, if any, has not, up to the present, been pointed out, nor, if non-existent, been proved so, is shown by an examination of the published records of the research on the subject.

"*Experimental.*

"To confirm or correct and to amplify the very meagre information available on the effects of steady E.M.F.s on filings coherers the following experiments were projected during the spring of 1900. They were made possible by the kindness of Dr J. Erskine-Murray, F.R.S.E., in whose laboratory they were commenced, and whose advice and assistance the writer had the good fortune to have always at call during the first phase of the work. The plan proposed was to submit to the influence of a steadily increased P.D. each of a large number of coherers of known degrees of sensitiveness, and to observe at what E.M.F. (if any) coherence was produced. Through Dr Murray's kindness, the writer had access to a very large stock of coherers which had been tested by the use of signals received on an air-wire, and whose general character and whose sensitiveness were fairly well known.

"These coherers were submitted to E.M.F.s supplied by a potentiometer arrangement. To avoid the possibility of abruptness in the changes of potential, a copper-sulphate solution potentiometer was adopted. This consisted merely of a long graduated glass tube containing dilute copper-sulphate solution, with one movable and two fixed electrodes. The fixed electrodes were of copper, and introduced and led away respectively the main current supplied by a battery of 10 volts. The movable electrode was also of copper, but was exposed to the electrolyte only at its extremity, the shank by which it was moved being insulated. Its position was read on the graduations of the tube, the value of the graduations in volts being roughly found by a separate experiment. One of the fixed electrodes (earthed as a rule) and the movable electrode formed with the intervening electrolyte a portion of a circuit which also included a moving coil galvanometer, a resistance of 12,000 ohms, and the coherer which was to be examined. By this means could be applied to the coherer a gradually increased E.M.F., ranging from zero to 10 volts, and that in so gradual a manner that there arose no probability of the creation of electrical surgings in the circuit external to the coherer. It might be added that a very few preliminary experiments showed the advisability of including in the coherer circuit a high resistance: its inclusion prevented the passage of any current considerable enough to damage the coherer. The coherers used were all of one type, were made by the same man from the same materials, and consisted of nickel filings between silver electrodes about 0.3 mm. apart, sealed in a vacuous glass tube.

"In every case coherence was found to take place with suddenness. Immediately coherence was indicated by the violent throw of the galvanometer mirror, the main current of the potentiometer was switched off and the position of the movable electrode read on the glass tube and recorded. Then the coherer was restored to its normal condition of high resistance by gentle tapping continued for a few seconds and the experiment repeated. It was found that the E.M.F. required to cohere the same tube varied as much as from 20 to 60 per cent. on successive occasions. The movement of any occupant of the room below affected the value of the figure obtained appreciably, while gentle agitation of the tube usually ensured coherence at quite low voltages. The effect of rougher shocks was, as Branly and others had shown previously, very irregular, and, as observation of the galvanometer mirror indicated, sometimes took the form of a rapid succession of coherences and decoherences. As regards the behaviour of different coherers, all exposed to identical circumstances, it was found, even when the greatest efforts were made to protect the tube from mechanical disturbances, that no law could be proposed to connect the E.M.F. at which coherence occurred with the sensitiveness as ascertained by testing on an air-wire—excepting in those two extreme cases in which the coherers were either extremely sensitive or extremely inert as regards signalling. In these two cases, indeed, low P.D.s for the one (from 0.1 to 0.5 volt) and high P.D.s for the other (from 6 to 10 or more volts) were the rule. In the case of very sensitive tubes the movements of the galvanometer mirror were extremely erratic at about the cohering voltage. No external cause could be definitely assigned to account for these vagaries, but they perhaps arose from mechanical disturbances originated at a distance and transmitted through the walls of the building to the apparatus table. A selection of the figures obtained is given in Table I. Each figure is the mean of three distinct observations obtained under circumstances as similar as possible. With these figures may be compared the results of independent tests made for commercial purposes on each coherer by examining its behaviour in receiving signals transmitted from a distant station.

---

* *Electrician*, August 23 and 30, 1901, by kind permission of the publishers.

† Many of the tables accompanying this article were obtained from coherers forming part of the stock of the Marconi Company. It is only by the company's kind permission that the writer is now enabled to publish them.—W. H. E.

"The liquid potentiometer was now discarded and a simple form of wire potentiometer installed in its place. The experiments outlined above were repeated on the same coherers, continuous contact between the slider and the potentiometer wire being purposely avoided. It will be seen from Table I. that figures were obtained which, allowing for the known aberrations, were for each coherer similar to those obtained with the electrolytic potentiometer.

"TABLE I.

Character of Coherer by Radiation Test.	Cohering Voltage.	
	Liquid Potentiometer.	Wire Potentiometer.
A. Too sensitive - - - -	0.05 0.2	0.15 0.1
B. Very sensitive - - -	0.6	·0.8
C. Moderate - - - -	2.0 0.4 3.5	1.2 1.2 4.1
D. Hard - - - - -	1.1 5.2	0.7 3.6
E. Very hard - - - -	0.3 4.2	0.5 5.0
F. Too hard - - - -	10+ 5	10+ 8

"So far, on the whole, mere confirmation of the results of other observers had been obtained. But now, it may be admitted, all doubts as to the possibility of coherence by the application of absolutely non-oscillatory E.M.F.s had, by the use of the liquid potentiometer, been removed. Moreover, it was now fairly well established that any electrical surgings produced by sudden connection with the source of E.M.F. had little or no influence in compelling coherence beyond that which their maximum voltage gives them. In other words, it appeared to be sufficiently demonstrated that coherence was an effect caused merely by P.D. Doubtful of finding any practicable mode of securing perfect freedom from mechanical disturbance, the writer next endeavoured to secure that the degree of mechanical disturbance should be uniform. This was more or less effectively managed by fixing the coherer to a framework kept in gentle agitation by an attached rapidly-vibrating bell-trembler. Unfortunately, another long series of measurements conducted on the same lines as before showed that little had been gained; the figures obtained from the same coherers, though being all smaller than by the previous method, were as irregular in value, and, apparently, as little related to the behaviour of the coherers under receipt of radiation as those set out in Table I.

"It now occurred to the writer to reduce the time of a single trial to the fraction of a second by allowing the hammer of a trembler to strike uninterruptedly the coherers under examination. During each quiescent stage between the blows coherence might take place and a current pass through the galvanometer. Decoherence would follow immediately and be succeeded by another coherence, and so on to any length of time. If uniformity in the vigour of the blows could be ensured, each consecutive cycle of operations within the coherer would resemble accurately the preceding one; and the galvanometer would integrate the pulsating currents traversing it and give their mean value. It remained to be seen whether the time allowed between the blows was sufficient for the production of coherence. The trembler first used performed about fifty vibrations per second. The coherer selected was one of moderate sensitiveness. Fig. 46 represents the results.

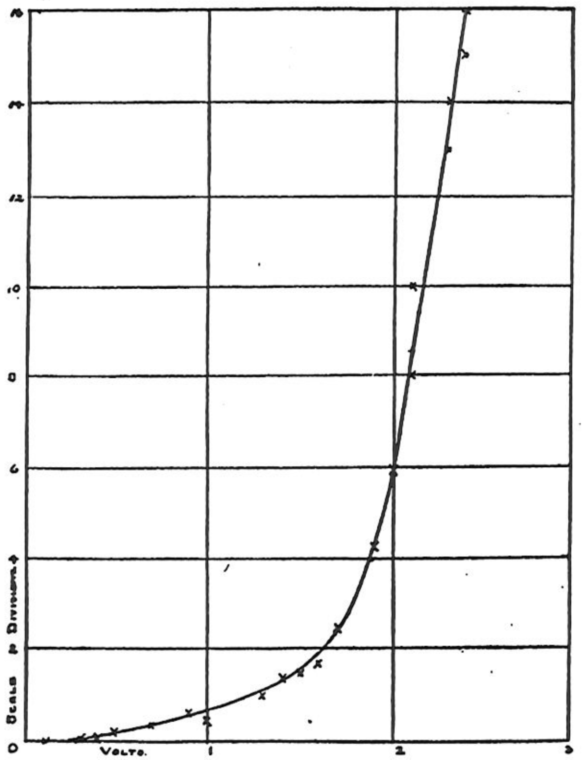


FIG. 46.

"After the lengthy experience of coherers which had been gained by the writer, the steadiness of the galvanometer reading and the certainty with which increase of deflection followed the movement of the jockey along the potentiometer wire seemed almost incredible. Occasionally, however, there were rather violent throws which sent the spot of light off the scale, and there were also sudden lapses which allowed the spot to fall towards zero. A number of coherers were roughly tried over, and from them figures giving similar curves obtained. It was, therefore, decided to remodel the apparatus and to prosecute thoroughly the new method. It was noticeable that in every case a decided change occurred in the conductivity of the coherer at voltages much lower than the critical voltages obtained by previous processes from the same coherers.

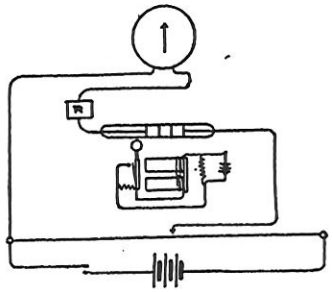


FIG. 47.

"The apparatus was wholly rearranged. Continuity of sliding contact being of no importance, a potentiometer was made by winding about 100 ft. of bare resistance wire on a long ebonite rod of circular section. When operated by six cells consecutive turns had a difference of potential of 0.02 volt very approximately. The contact piece moved parallel to the axis of the ebonite rod. A moving-coil mirror galvanometer was shunted till its sensitiveness was such that 1 cm. on the scale corresponded to 3 microamperes, A bell-trembler especially capable of adjustment as to stroke and speed was obtained; and a non-inductive resistance of 10,000 ohms was placed in the coherer-galvanometer circuit.

"A diagrammatic plan of the apparatus is given in Fig. 47. With this disposition of the apparatus the characteristic curves were plotted for a large number of tubes, the circumstances of each experiment being maintained for all invariable. A selection of the curves so obtained is given in Fig. 48. From this selection will be seen what was merely emphasised by all the other

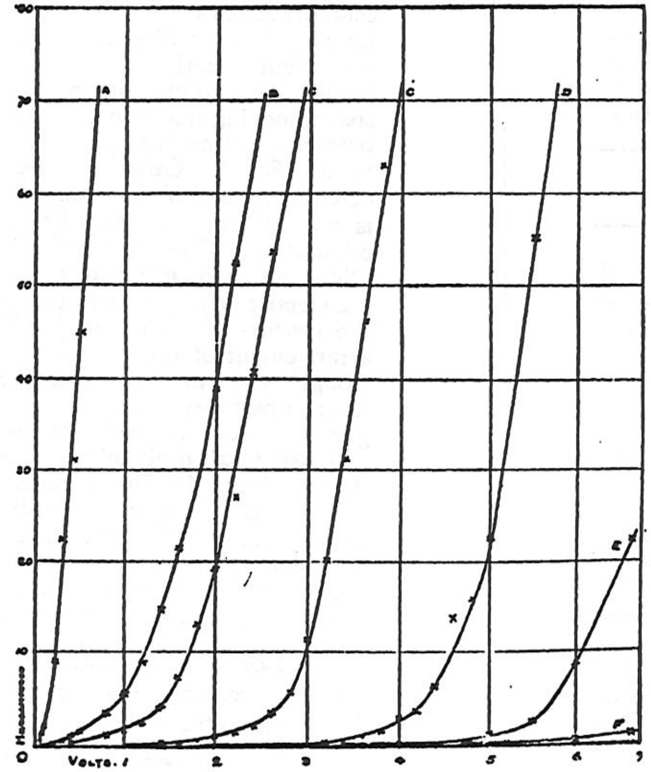


FIG. 48.

The curves *A*, *B*, &c., are from different coherers in decreasing order of sensitiveness.

curves obtained, that the general position of its curve on the chart indicates exactly the sensitiveness of a coherer as judged by the radiation test. It should be noticed that the occurrence of rapid coherence is on these curves indicated by their convexity towards the axis of E.M.F.—were the conductivity of the coherer constant the curves would degenerate into sloping straight lines passing through the origin. With all the coherers examined, excepting those of known and remarkable non-sensitiveness, some curvature was apparent under comparatively small E.M.F.s. Further, there was in no case, as the applied E.M.F. was increased, any sudden increase in the current; but, on the contrary, always a gradual growth in its value. Again, it will be noticed that when the applied E.M.F. becomes great enough the relation between current and E.M.F. becomes approximately linear, indicating that coherence is now increasing uniformly and slowly. In order to examine more closely whether coherence could be

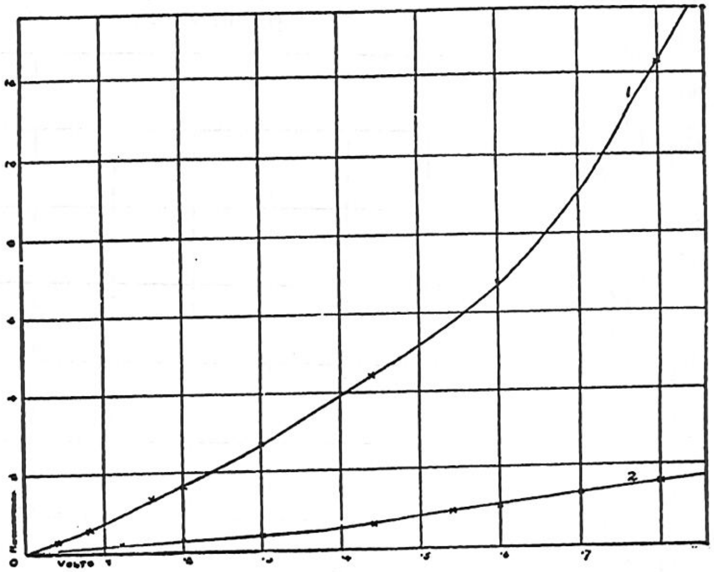


FIG. 49.

traced at rather low voltages the sensitiveness of the galvanometer was raised by changing the shunt, and two of the coherers whose curves are given in Fig. 48 submitted to low E.M.F.s, the frequency of the trembler being unaltered. Fig. 49 gives the curves so obtained. They seem to indicate that the fall of resistance of a coherer commences very early, but, also, that no great change-rate is reached till a certain E.M.F. is applied which is different for each coherer. Another and similar trial on some very non-sensitive tubes, in which P.D.s up to 9 volts were used, showed that the linear portion of the curve for most coherers could, if desired, be reached. Two of these curves, which are in every feature similar to those in Fig. 48, are given in Fig. 50.

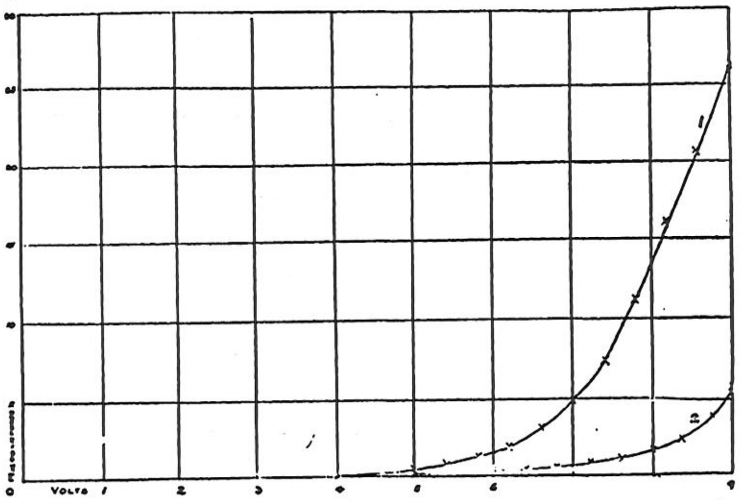


Fig. 50.

"In the late summer opportunity arose of applying this method of examination to a very large number of coherers. The final conclusion which these trials led to need here be merely stated. The complete correspondence between the sensitiveness of a coherer to electro-magnetic radiation and the position on the chart of the characteristic curve obtained by this method was fully demonstrated.

"The general results of the mass of observations briefly described in the preceding pages, and a study of the characteristic curves, led the author to a kinetic theory of the filings coherer, which makes the typical coherer consist of filings free to move throughout the space of a narrow crevasse bounded at its ends by plane conducting faces.

"When a difference of potential, steady or oscillatory, is established between two opposed plane conductors separated by a distance which is small compared with their own magnitude, a fairly uniform electric field is created between them. Any conducting piece of matter, not spherical in shape, moving freely in this field, will experience a couple tending to place it, in general, with its longest axis parallel to the field.* Other particles present will be similarly acted upon, and if they come to rest while the electric field is maintained, they may be expected to exhibit distinct orientation. The degree of orientation among the mass of filings will evidently bear some relation to the strength of the electric field, that is, to the applied E.M.F. In this state the process of 'coherence' will be easier than when the arrangement of the particles is fortuitous. If we take Dr Lodge's view, that an actual welding occurs between contiguous particles till complete chains are formed across the gap, it must be noticed that the perfection of the weldings will also, in all probability, depend on the E.M.F. producing them. Thus, in filings coherers, the writer thinks, two distinct actions—one, the mechanical, resulting in orientation of the particles, the other, the true 'coherence' phenomenon, resulting in weldings—occur, and these are both dependent on the applied E.M.F. It is the author's contention that the share of the mechanical action is great."

Dr Eccles next treats the subject mathematically and describes experiments confirmatory of his theory, and finally states his main conclusions as follows:—

"**Conclusion.**—The first series of experiments with the liquid and wire potentiometers demonstrated satisfactorily that electrical surgings, such as are no doubt produced in any circuit to which an E.M.F. is abruptly applied, had no effect—as surgings—in producing coherence. From this result alone it may be concluded fairly that, as Branly and others have always insisted, the phenomenon of coherence is an effect of E.M.F. merely. But, besides, these first experiments brought prominently before us the many vagaries which have caused the filings coherer to be universally regarded as an instrument of erratic and unaccountable behaviour.

---

* This much, the author believes, has been suggested before, but he has not been able to find any distinct statement.—W. H. E.

"The next portion of the work led to the invention of a very general and powerful method of examining filings coherers. By the use of this method all the anomalies which have hitherto accompanied the manipulation of a coherer seem to disappear, and a curve is obtained which expresses most definitely all the characters of the coherer from which it is drawn. It may be termed a true quantitative method of investigating the qualities of a coherer. The curves indicate plainly that very definite and invariable laws govern the action of a coherer. They prove, besides, that coherence is a continuous phenomenon, and that there can be no true 'critical voltage.' Moreover, the complete agreement which the author found, during his work with hundreds of coherers, between the sensitiveness to electro-magnetic radiation and the position on the chart of the curves of the respective coherers, prove most emphatically that the ultimate causes of the whole phenomenon of coherence are the same with oscillatory and with non-oscillatory E.M.F.s. Thus those common expressions, 'the impinging of waves,' and 'the incidence of radiation on a coherer,' might, with advantage, the writer thinks, be deleted from our phraseology. For the production of coherence by radiation is in all probability entirely due to oscillations of potential set up in the coherer connections."

The results of Dr Eccles' admirable research may be summarised in a few words:—(1) The filings coherer acts on the application of a difference of potential to its terminals, and this voltage may be either continuous or alternating. (2) Any small voltage is sufficient to produce some current, but in the neighbourhood of a certain voltage, which is different for each coherer, the resistance decreases very rapidly, allowing a correspondingly rapid increase of current, which welds the filings, and causes a further

decrease of resistance. (3) The sensibilities of coherers for steady voltages are proportional to their sensibilities for oscillatory voltages. (4) The whole phenomenon may be explained mathematically on the supposition that the action takes place in two stages—firstly, the turning of the particles into line under the influence of the electrostatic force, and secondly, a welding together of their ends, thus brought together, owing to the passage of a current.

Lieutenant Solari, of the Italian Navy, discovered that a small drop of mercury between two iron plugs forms a very sensitive self-restoring coherer. Its disadvantage lies in its need for frequent adjustment.

Dr Muirhead has improved upon this by using a small rotating disc of steel which grazes the surface of a pool of mercury covered with a film of oil. The continual motion of the disc prevents mercury from sticking to the steel, and at the same time ensures that the surface of the mercury is clean. One advantage of this coherer is its low resistance when cohered, which makes it possible to use it in connection with a siphon recorder or other sensitive telegraph instrument without interposing a relay.

Anti-coherers.—If the effect of electrical oscillations is to increase the resistance of a detector, the apparatus is called an anti-coherer. The most important of these are perhaps the electrolytic device used by Dr de Forest, and Mr Brown's lead peroxide detector, both described in a later chapter. Unlike the metallic contact coherer, which may be cohered by the electric jigs whether the local battery is connected or not, the anti-coherer is only maintained in its sensitive state by the action of a steady voltage in its circuit, and is restored to its original state by the same agency after the reception of a signal. In the case of the coherer, mechanical vibrations perform a similar function. Carbon coherers are, under ordinary circumstances, self-restoring. It seems likely, however, in default of experimental evidence to the contrary, that the restoration may be due to mechanical vibration, which enables the contact again to attain a more or less stable state of equilibrium.

Messrs Duddell and Taylor's Measurements of Voltage in the Coherer Circuit.—With the kind permission of the authors, and of the Council of the Institute, I append a quotation from the paper,* read to the Institution of Electrical Engineers in 1905, in which the authors give an estimate from experimental data of the actual voltage in the coherer circuit:—

"Though no precise measurements bearing on the point were made, it may be taken in view of the manner in which the coherer receiver used at intervals during the experiments responded at the longer distances, that the E.M.F. of 6.6 volts given in the previous paragraph was about eight times stronger than necessary to get signals on that particular coherer. The critical R.M.S. electromotive force during each train in the receiver antenna required to operate the coherer, would therefore be about $\frac{6.6}{8}=$ 0.8 volt. This was not the actual voltage applied to the coherer terminals, however, because the coherer was always connected in a secondary circuit tuned to resonance, in which it may be taken that the E.M.F. was magnified, perhaps ten times, giving 8.0 volts per train (R.M.S.). In this secondary resonant circuit a special form of construction has been adopted, and every precaution taken to reduce the damping to a minimum. To get an idea of the maximum voltage attained during a train of oscillations in this circuit, it is necessary to take into consideration the increment and decrement of the train. Allowing for this, it is thought safe to assume that an actual maximum E.M.F. of about four or five times the R.M.S. figure, viz., about 40 volts, should be available in the coherer resonant circuit to give good signals. As in practical work it would be necessary to provide a considerable margin above the figure, it is clear that the maximum voltages produced are not of a very small order."

---

* *Journal I.E.E.* vol. 35, No. 174.

CHAPTER V.

DETECTION OF OSCILLATORY CURRENTS OF HIGH FREQUENCY BY THEIR EFFECTS ON MAGNETISED IRON.

THE effect of an oscillatory magnetic field on magnetised steel or iron differs considerably in different circumstances. A permanent change, however, of the state of magnetisation of the iron is almost always apparent. The results depend on the qualities and magnetisation of the material, on the intensity and character of the oscillations, and on the relative directions of the magnetisation and the oscillatory field. It has been known since the earlier part of last century that the discharge of a Leyden jar will magnetise or demagnetise steel needles. Professor Joseph Henry made a large number of observations on the phenomena, and threw much light on the nature of the discharge of a condenser, but it was not until 1895 that the possibility of detecting, by this means, electric waves which had travelled considerable distances was proved by Mr Rutherford. In that year, by using a large Hertzian oscillator with plates about 1 by 2 m. and a resonator consisting of two copper rods about 30 cm. long, he was able to detect the radiations at distances up to three-quarters of a mile. The rods of the resonator were connected by a small helix of fine wire, in the axis of which was placed a magnetised needle or bunch of very fine steel wires. A magnetometer indicated the amount of magnetism in the needle, and decrease of its deflection showed the arrival of the waves. After each observation it was necessary to remagnetise the needle, no automatic arrangement for this purpose being provided. Professor Rutherford suggested to me in 1900 that the oscillations might be made to record themselves on a steel band, as in the telegraphone. I was, however, too fully employed with other work at the time to undertake the experimental work necessary to produce a practical wireless telegraph receiver.

In 1900 the author constructed an automatic magnetic receiver. It was similar to Rutherford's first apparatus, but the remagnetisation of the needle was effected by a local battery whose circuit was closed by the motion of the magnetometer. This appears to be the first *telegraphic* receiver in which the magnetic detector was employed.

Three years later, in 1903, Mr Marconi patented two forms of magnetic detector somewhat different in principle from those already described. Instead of allowing the steel to remain demagnetised for an appreciable time and then remagnetising it by closing a local circuit, he applied a slowly alternating field to the iron core. As the core goes through its cycle of magnetisation, the latter lags behind the applied force. If, however, an oscillatory field of high frequency is suddenly superimposed on the slowly alternating one, the molecules of the iron are shaken up and the lag instantaneously disappears, the magnetisation jumping at once into the condition corresponding to the applied field. A similar effect is produced by a mechanical shock. The sudden change in induction through the core is observed by means of a telephone receiver in circuit with a coil of wire round the core of the detector. On the arrival of oscillatory currents at the detector, the momentary current induced by the change of magnetic induction causes a click in the telephone.

Mr Marconi's second magnetic detector attains a similar end in a somewhat different way. An endless band of fine insulated iron wires is kept moving at about 8 cm. per second in the direction of its length round two wooden pulleys. Near to one part of the band two horse-shoe magnets are fixed, two similar poles being together, and the opposite ones farther along the band on either side. A large number of lines of force pass into the band under the central poles, and after travelling some distance in

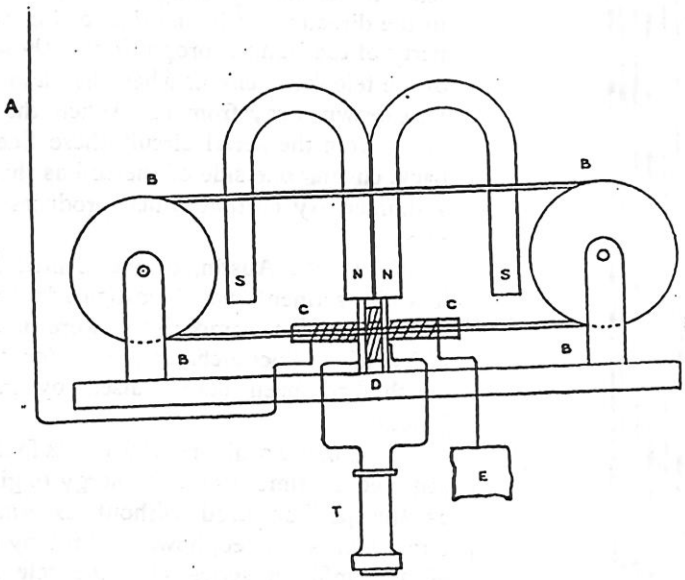


FIG. 51.—MARCONI'S MAGNETIC DETECTOR.

A, Aerial Wire; *E*, Earth-Plate; *B B*..., Iron Band round Pulleys; *S N*..., Permanent Magnets; *C C*, Primary Winding on Glass Tube through which the Iron Band Travels; *D*, Secondary Winding; *T*, Telephone Receiver. In a more recent form of instrument only one magnetic circuit is used, the outer poles being opposite instead of similar magnetic poles.

either direction along it reach the outer poles of the horseshoes. Wound on a glass tube, through which the band passes at this point, are two coils of fine wire. The inner one is connected to the aerial and earth wires, and the outer to the terminals of a telephone receiver. As the band travels slowly along, the lines of force are drawn out in the direction of its motion owing to the retentive property of the iron; a proportion of those which cut one side of the telephone circuit when the band is at rest are, therefore, drawn away from it. When the oscillatory currents arrive from the aerial circuit these lines are freed and fly back, cutting one side of the coil as they go. The result is a momentary current which produces a click in the telephone.

Dr L. W. Austin, of the United States Naval Wireless Department, has investigated the properties of this detector. The comparisons were made with the sensibility of a zincite-chalco-pyrite (or "perikon") detector which had been standardised by means of a thermo junction.

Used in the ordinary way, it was found that the magnetic required 2.1 times as much energy to give an audible sound as the perikon used without external E.M.F. Further experiments showed, however, that by putting a condenser of 0.05 mfd. in series with the telephone, thus roughly tuning this circuit to the spark rate of the signals, the sensibility of the magnetic was nearly doubled. These experiments were made with a wave-length of 900 m. Other experiments showed that the magnetic, with tuned telephone, was approximately one and a half times as sensitive as the perikon for a wave-length of 3,000 m. For a wave-length of 2,000 m. they were nearly equal, and for a wave-length of 350 m. the perikon was nearly five times as sensitive as the magnetic.

By experiment and calculation Dr Austin also showed that these differences were mainly due to the difference of the effective resistance of the magnetic at different frequences. For instance for $\lambda = 350$ m., $R^1 = 110$ ohms, while for $\lambda = 3{,}000$ m., $R^1 = 10$ ohms. It was found that the loudness of the signals in the telephone attached to the magnetic is not proportional to the square of the current, but more nearly to the 1.4 power.

Each spark at the transmitter thus makes an audible sound in the receiver. As in other forms of wireless telegraph a short succession of sparks constitute a dot, and a long one a dash. Messages in the Morse code are, therefore, transmissible. This receiver is more sensitive than the coherer, and is also more easily adjusted. It has come into very general use on account of these advantages, but its inability to actuate a recording instrument is in certain circumstances a drawback, particularly if the operator be not extremely expert and the message be in cypher. In Post Office work over the ordinary wires the difficulty is obviated by the use of an automatic type-printing telegraph where possible, thus eliminating errors which might occur at the receiving end. In other cases the repetition of the message, back from office to office, is insisted on by the Post Office as essential to accuracy, when cypher or code words occur in it.

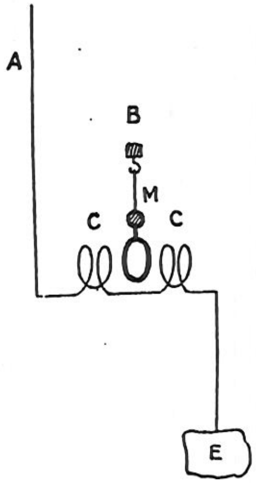


Fig. 52.—Fessenden's Electro-magnetic Receiver.

A, Aerial Wire; *B*, Support for Moving Parts; *M*, Small Mirror, below which is a Light Ring of Wire.

In 1899 Professor Fessenden invented several forms of magnetic receiver. The earliest depends on the reaction between a closed circuit of low resistance and another circuit, or coil, in which oscillatory currents are flowing. The closed circuit is a very light ring of wire to which a mirror is attached, the whole being suspended by a fine fibre. The oscillatory currents flow through a fixed coil, inducing currents in the ring which repel those in the fixed coil. The signals are read by the deflections of a spot of light from the mirror, as is frequently done in submarine cable work. No iron or steel was used in this instrument.

His second detector, shown in Fig. 53, is entirely different in principle, and depends on the magnetic properties of steel. A fine steel wire is included in the line between the aerial and earth wires, with its length at right angles to a powerful magnetic field. One end is also connected to a local battery circuit, the other pole of which forms a terminal, very close to, but not in contact with the steel wire. The wire is normally cross magnetised by induction from the magnetic field, and is therefore subject to a force tending to pull it into the position where the field has greatest density; it thus sags in the direction of the poles of the fixed magnet. The oscillatory currents along the wire suddenly reduce the permeability, or cause some other change which is equivalent in effect, and the wire springs up and presses the contact, completing the local circuit. The use of a recording instrument in the local circuit seems possible with this detector, though the telephone would no doubt be more sensitive. On the whole the apparatus does not appear suitable for the detection of very minute currents.

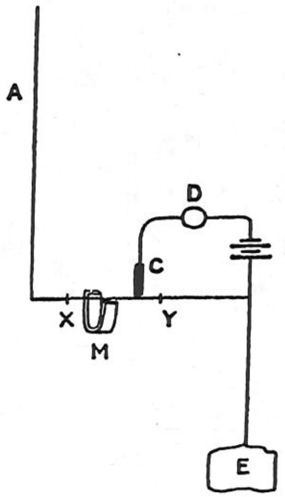


FIG. 53.—FESSENDEN'S MAGNETIC RECEIVER.

A, Aerial Wire; *X Y*, Thin Steel Wire; *E*, Earth; *M*, Permanent Magnet; *C*, Fixed Carbon Microphonic Contact Piece; *B*, Battery; *D*, Galvanometer.

In the recently invented "Einthoven" galvanometer, which is extraordinarily sensitive to continuous currents, a single wire in a very strong magnetic field is also used, but the wire is of non-magnetic material; with oscillatory currents it would therefore tend to vibrate in time with the oscillations at a frequency too great to be observable, even if the forces concerned were sufficient to cause a mechanical vibration of more than infinitesimal amplitude; the adaptation of this instrument to the needs of wireless telegraphy seems therefore unlikely.

In 1904 Mr Walter and Professor Ewing patented a magnetic detector based on the discovery that oscillatory currents *along* a fine steel wire increase its hysteresis. A description of this apparatus was given in a communication to the Royal Society in 1904,* from which the following is an excerpt:—

> "It occurred to us to exhibit the alteration in hysteresis by applying the principle which is used in an instrument invented some years ago by one of us for the mechanical measurement of hysteresis. In that instrument† the hysteresis is measured by the mechanical couple between a magnetic field and the iron, when either the iron or the magnet providing the field is caused to revolve. Thus, if the field revolves, the iron tends to be dragged after it, as a consequence of hysteresis in the reversals of its magnetism, and if the motion is prevented by a spring or other control, it assumes a deflected position. Suppose, now, the electric oscillations to act on it, any change of the hysteresis caused by them will be exhibited by a corresponding change in the deflection. We anticipated, in accordance with the generally accepted view that hysteresis is reduced by the oscillations, that their presence would be detected by a fall in the deflection.
>
> "With this expectation an experimental apparatus was arranged, consisting of an electro-magnet, capable of being rotated on a vertical axis by an electric motor. The magnet poles were bored out circular, and between them was sus-

---

* *Proc. Roy. Soc.* vol. 73, February 1904, by kind permission of the Council.

† *Journ. Inst. Electr. Engineers*, vol. xxiv. pp. 398-430, 1895.

pended, by a phosphor-bronze strip, a ring made up of three thin, flat annuli of soft iron, clamped together, and provided at the foot with an axial pivot. The ring was free to turn inside of two bobbins wound with fine copper wire, the windings being at right angles to the plane of the ring. Through these copper windings, electrical oscillations, produced in the usual manner by means of a distinct spark-gap, were passed.

"The first experiments resulted in a very small deflection from the position due to normal hysteresis, indicating, as was expected, a decrease of hysteresis when the oscillations arrived. The apparatus was also tested with an alternating current of about 100 periods per second in place of the oscillations, with the effect that the normal hysteresis deflection was almost entirely wiped out.

"Various other forms were also tried with indifferent results, when it occurred to us that there would be advantages in passing the oscillations through the magnetic material itself, making it of magnetic wire. A small bobbin was therefore wound with insulated soft iron wire, and the ends soldered to the upper and lower halves of the spindle, which was itself divided at the centre, the upper half bearing the controlling spring, and the lower dipping into mercury, from which a connection led to the other terminal. On passing oscillations through this winding, a remarkable and unexpected result was obtained. The change of deflection was much more marked than in the former experiments, and was in the opposite sense, indicating an increase of hysteresis while oscillations were present. Afterwards, hard steel wire was substituted for the soft iron, and a very great increase in the effect was observed, still in the same direction—that of increase of hysteresis.

"Owing to these encouraging results, it was decided to continue the experiments in this direction, abandoning the older form, in which a decrease of hysteresis was dealt with. The first bobbin constructed was about $\frac{5}{16}$ inch in external diameter, and had a vertical wire space of $\frac{1}{4}$ inch. The winding was a single No. 32-gauge iron wire, double cotton-covered, wound straight round from beginning to end. Later, No. 40 and No. 46 steel wires were employed, of which the latter gave the best results.

"It was soon noticed that any method of increasing the oscillatory current in the wires, as by winding the bobbin with two wires having a slightly unequal number of turns, was of advantage in giving a larger deflection. Later a fine copper wire secondary, wound on the bobbin parallel to the magnetic wire, was tried, first with the ends insulated, and then with the ends soldered together. A marked increase in deflection was observed when the secondary was closed, showing that the magnetic nature of the wire itself was influential. Accordingly, a bobbin was then wound with insulated steel wire, doubled back on itself. This

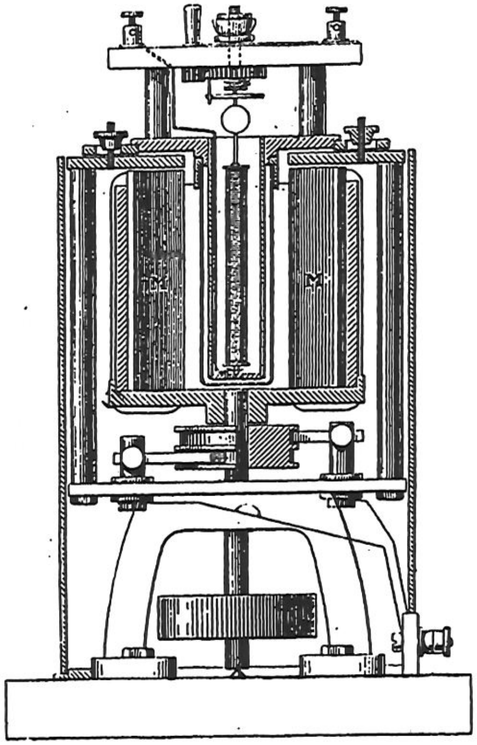


FIG. 54.

non-inductive winding gave by far the best results hitherto attained, and is now used, except when special results are required.

"The instrument, though described as a detector of electrical oscillations, may be said to measure rather than detect, giving quantitative as well as qualitative results, and being capable of regulation from a sensibility of the same order as that of an average coherer down to practical insensibility to powerful sparks in the same room.

"In the instrument, as shown in the figure, the electromagnet takes the form of a ring capable of moving round a vertical axis, and is provided on the interior with two long wedge-shaped pole-pieces, M, M, the current to the winding being supplied through brushes bearing against insulated rings below. The magnet is made to revolve by an electro-motor, the best speed being about five to eight revolutions per second, but the electro-magnet may be replaced by a permanent magnet system giving a similar field. A structure is built up, external to the magnet, to support the vessel containing the pivoted bobbin and its centring arrangements. The bobbin itself is made of bone, and is about two inches long. It is provided with a steel spindle at each end bearing in a jewel hole, the two halves of the spindle being insulated from one another. The winding, which is, as far as possible, non-inductive, consists of about 500 turns of No. 46 gauge hard-drawn steel wire, insulated with silk. The bobbin is immersed in petroleum, or a mixture of petroleum with thicker mineral oil, which serves the double purpose of fortifying the insulation, and giving the damping effect necessary to steady the deflection due to the drag of the revolving magnet. Readings are taken by means of a spot of light, as with speaking mirror galvanometers, but a siphon-recording attachment has been fitted, and any form of contact for working a relay could be employed.

"The detector, as before mentioned, gives quantitative readings, and, in some cases, the deflection may be too large to be easily read by the scale. For this purpose a variable shunt is provided, by which the deflection can be regulated.

"For the purpose of wireless telegraphy, the instrument has the advantage of giving metrical effects. The benefit of this in facilitating tuning, and in other respects, need not be insisted upon."

Mr Walter has more recently invented another form of self-restoring magnetic detector based on a quite different principle and capable of producing unidirectional—that is, direct—currents when excited by the received oscillations. This forms in theory an advance on previous detectors, and with his kind permission I quote his description of the apparatus, given in a paper to the Royal Society in April 1906: *—

"The method was arrived at as a result of experiments in connection with an instrument previously described,† to determine the cause of the increase of hysteresis loss as a result of the action of oscillations. It was found that the increase is due to a great extent if not entirely to the increase of induction produced, to which increased induction a largely augmented hysteresis loss corresponds at the field strength employed. Working on this basis, it was thought that such an increase of induction might serve as a means of furnishing continuous unidirectional currents, by generating an unidirectional (commuted) E.M.F., *i.e.*, by making conductors cut the lines of force in a magnetic field, and causing the oscillations to act upon a magnetic mass undergoing reversals of magnetism in the magnetic field of the generator, whereby the E.M.F. generated should be augmented; a second equal E.M.F. being opposed to the first, so that normally there is no external potential difference. In such a case a continuous unidirectional current should be obtainable during the time that the oscillations are acting upon the magnetic mass.

"An experimental apparatus was accordingly made, a diagrammatic plan of which is given in Fig. 55. Two ebonite bobbins, B, B_1, mounted on the same spindle, are rotated in the field of two horse-shoe permanent magnets, NS, N_1S_1, these bobbins being wound, in a similar manner

---

* *Proc. Roy. Soc.* A. vol. 77, April 1906, by kind permission of the Council.

† Walter and Ewing, *Roy. Soc. Proc.* vol. 73, p. 120, 1904.

to those illustrated in connection with the pivoted bobbin detector previously referred to, with some feet of steel wire of suitable resistance. A winding of two coils, W, W′, at right angles to one another, of a hundred turns, is placed on each bobbin, at right angles to the plane of the steel wire winding, as in a drum armature, corresponding coils, *i.e.*, W and W_1, W′ and W'_1, being connected in such a way that the E.M.F.s generated are equal and opposite. The ends of the windings are connected to the segments of a 4-part commutator, C. (For the sake of clearness only one pair of corresponding windings, of one turn each, is shown connected in Fig. 53.) The steel wire windings of the two bobbins are exactly alike, the ends of one winding being insulated, while those of the other are connected to a pair of slip-rings, *r*, *r*, and brushes, by means of which the oscillations can be passed through the winding.

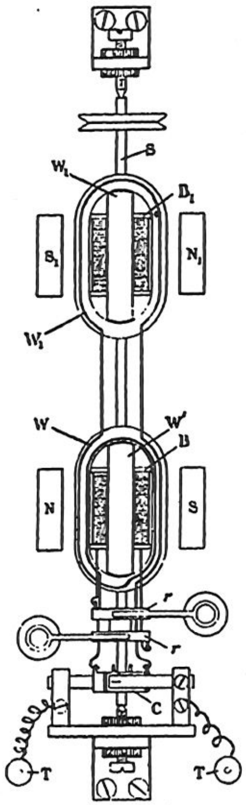


FIG. 55.

"On testing this apparatus in the normal condition, with the armature driven by a small electric motor, and no oscillations acting, there was no potential difference at the brushes, the zero of a sensitive Ayrton-Mather galvanometer connected to the terminals, T, T, remaining undisturbed. On waves arriving, a steady deflection on the galvanometer was obtained, in a direction corresponding to an increase of E.M.F. generated by the armature (bobbin) acted upon by the oscillations. On the oscillations ceasing the galvanometer deflection returned to zero. The effect naturally was very small in the first experiments, but it has been found that by suitably designing the magnetic winding and proportioning the turns in the armature winding a quite considerable sensibility is obtained, and this is continually being improved upon. The usual speed employed is about five to eight revolutions per second; higher speeds have been tried and give a larger effect, but the zero is not so steady.

"The model illustrated is not adapted to give the best results, this form having been chosen solely for convenience in construction. A considerable length of the winding on the armature is "dead" wire, and hence in a new model being constructed, the armatures resemble small Gramme ring structures, in which the wire is more effectively utilised.

"The results obtained with the first form of the apparatus led to the idea that the magnetic mass might be located elsewhere in the magnetic circuit of M, such as at B in Fig. 56, undergoing slow continuous reversals at the most favourable speed, and an ordinary ring armature, A, be used, which latter could then be run at a much higher speed so that a proportionately greater external potential difference as a result of oscillations acting could be anticipated, two identical generators, opposed to one another of course, being employed as in the previous method. The few experiments made in this direction have, however, not given good results up to the present, but this is considered to be due rather to the experimental apparatus employed than to the inapplicability of the method."

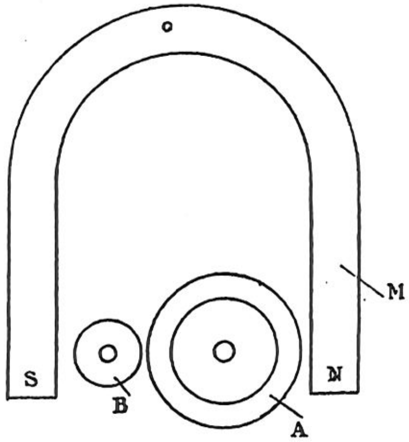


FIG. 56.

Dr W. H. Eccles has recently investigated the phenomenon under conditions which approximate very closely to those obtaining in actual wireless telegraphy. He has kindly permitted me to make the following excerpt from his paper:[*]—

"In the experiments to be described, an endeavour has been made to turn the difficulty arising from the skin-effect. Oscillations so feeble have been used that they affected only the outermost layers of the iron wires employed. The cores of the iron wires have, therefore, not been used.

"Other and great difficulties arise in the matter of producing oscillations of determinate and invariable character. Maurain, in the greater part of his work on this subject, appears to have used the oscillations that passed through a helix in series with a Leyden jar kept sparking strongly and continuously by means of an induction-coil. Russell,[†] in some recent experiments, applied to his iron the oscillations passing through a coil connected directly in series with a small induction-coil. This last method appears to the writer to subject the iron to very violent treatment of a nature not easily described accurately; for how far the mere surgings of secondary current overwhelm in importance the genuine oscillations, it will be difficult to say. Piola,[‡] again, worked with highly damped oscillations, because, he found, such oscillations produce the highest effects. He has, indeed, following Rutherford, used this fact in determining the damping factor of a circuit. But in the present investigation these sources of indeterminateness have, as far as might be, been avoided by using a single train of waves instead of a continued torrent of such trains, and by using oscillations as little damped as possible.

"The present paper deals solely with oscillations whose magnetic field is along the direction of the principal field.

"In these experiments fairly soft Swedish charcoal iron, aged, and not freshly annealed, was taken a large number of times round any chosen magnetic cycle (as in ordinary magnetic testing) till what may be called a cyclic state was attained. The field was then given any desired value, and the iron submitted to a single train of oscillations. This was managed by generating the oscillations on a helix surrounding the iron wire. The consequent alteration in pole strength was observed by the deflexion of a magnetometer mirror. These processes were all repeated a number of times for each selected point of the cyclic curve. The figures given in the table below are thus each the mean of a number of observations.

"In detail, the apparatus adopted consisted of two straight solenoids each of 3,270 turns of No. 20 copper wire wound in six layers on a length 59 cm. of split brass tube. They were placed horizontally on one and the same magnetic east-west line, but on either side of a mirror magnetometer. The magnetometer-needle was in the common axis of the two solenoids. The solenoids were connected in series, and so adjusted in position that when a large current was passed through them the magnetometer-needle was undisturbed. A liquid resistance, a Weston milliammeter, suitable switches and commutators, and a battery of six secondary cells completed the solenoid circuit. The coil destined to be the seat of the oscillations consisted of 1,252 turns of No. 26 copper wire wound in a single layer on 70 cm. of a glass tube 0.5 cm. in external diameter, and had a resistance of about 3 ohms. The whole coil was wrapped in paraffined paper and pushed into the brass tube of the east solenoid.

"The iron wire examined was unannealed Swedish charcoal iron, diameter 0.749 mm., and was used always in lengths of 56 cm. Its characteristic curve is given in Fig. 57. The magnetometer was a silk-suspended mirror carrying four very small magnets; readings were taken on a scale distant 88 cm.

"The object in employing twin solenoids is clear. By placing equal amounts of iron wire in each solenoid and adjusting their positions carefully, the magnetometer deflection could be kept very slight whatever magnetic variations the iron was taken through, the iron in the one solenoid compensating that in the other.

"It was then permissible to exalt greatly the sensibility of the magnetometer. This was done by reducing the controlling field at the needle by means of an auxiliary permanent magnet.

---

[*] By kind permission of the Council of the Physical Society and of the publishers of the *Philosophical Magazine*.

[†] *Proc. Roy. Soc. of Edin.* Nov. 20, 1905.

[‡] *Elettricista*, iv. p. 145, May 15, 1905.

"In the experiments, three iron wires insulated from one another and tied in a bundle were used in each solenoid, the group in the east coil lying, of course, in the glass tube on which the oscillation-coil was wound. The inner ends of the wires were 9.3 cm. distant from the magnetometer-needle. The field at the needle was reduced to 0.034 C.G.S. unit. With these arrangements, such a sensibility was attained that on certain days of August last the strokes of distant lightning, not visible in London,* were easily perceptible in the laboratory by their effects on the iron in the oscillation-coil.

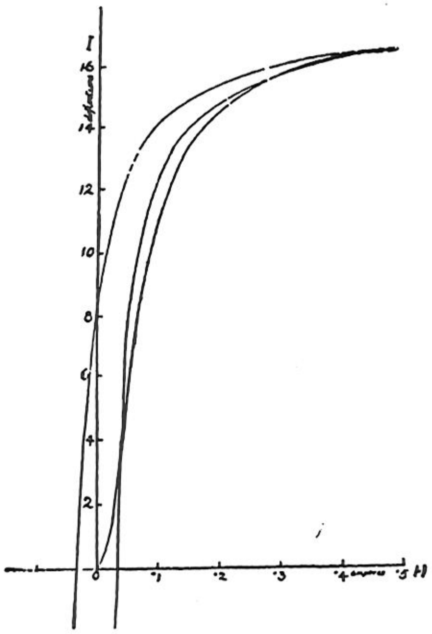


FIG. 57.

"The oscillations used were produced by leading the free east end of the oscillation-coil, that is the end distant from the magnetometer, to one side of a micrometer spark-gap. The other end of the oscillation-coil was left insulated. The poles of the spark-gap were connected to the terminals of a diminutive influence machine, that pole not connected to the oscillation-coil being, besides, earthed. Thus, when the handle of the influence machine was turned through a certain angle (depending on the spark-gap) at a speed easily learned, a spark occurred which set up oscillations in the coil. The spark-length finally settled upon was about half a millimetre. It was found possible in this way to get over and over again practically the same magnetometer deflexion for every spark, provided the effect of previous oscillations was wiped out by taking the iron through a cycle. As these small sparks were usually inaudible, their occurrence was recognised by the sudden deflexion of the magnetometer-needle.

"The calculated period of the stationary waves on the oscillation-coil is 5.7×10^{-7} second.

"A typical set of operations was as follows:—The iron was demagnetised by reversals. An amplitude of cycle being then decided upon, the iron was taken a number of times through that cycle. This last operation was stopped at the point settled upon for the observations, and the magnetometer reading taken. A spark was passed, and the magnetometer again read after thirty seconds. A complete cycle was now performed ending at the same point as before, and another spark passed, and so on. Usually, about twenty points on a cycle were examined by four or six observations at each. In this paper, however, the effects of the spark are recorded as if the observations had been taken only on the ascending half of the hysteresis curve; the figures given being in fact the means of the measured effects at points symmetrical with regard to the origin on the ascending and descending branches.

TABLE I.

Current in Milliamperes.	-150	-100	-75	-50	-40	-30	-20	0	20	30	40	50	75	100	150	200
50 cycle	...	...	...	...	0.06	0.10	0.13	0.28	0.38	0.45	0.60	0.55	...	...	...	...
100 cycle	...	...	...	0.27	...	...	...	0.68	1.08	...	...	1.26	1.30	1.18	...	...
150 cycle	...	0.20	...	0.44	...	...	...	0.92	...	1.32	...	1.51	1.62	1.57	1.19	...
200 cycle	0.20	0.36	...	0.68	...	...	...	1.22	...	1.57	...	1.71	1.75	1.55	0.93	0.38

"In this table the figures given can be reduced to absolute measure as follows:—The numbers at the top of each column and down the left column, representing the

---

* "The newspapers gave accounts of thunderstorms in Hertfordshire."

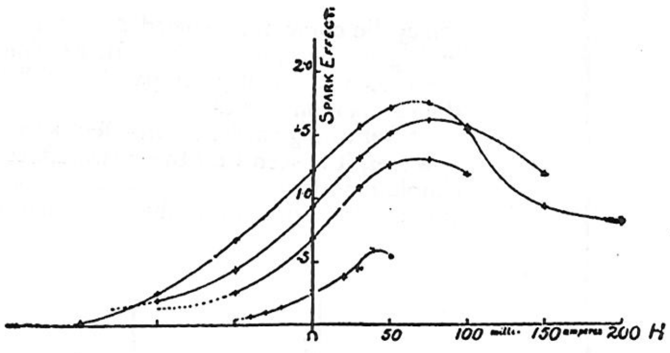


FIG. 58.

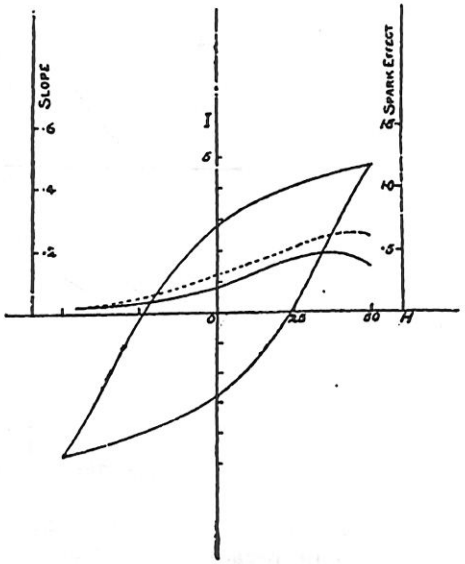


FIG. 59. The dotted curve shows spark-effect.

current through the solenoids in milliamperes, yield when multiplied by 0.0696 the magnetic field in C.G.S. units applied to the iron. The deflexions in the body of the

table give the change in pole strength, due to the spark, by multiplying by 0.017; yield the volume-average change of intensity of magnetisation by the factor 1.27; or give change of total magnetic moment of the affected specimen by the reducing factor 0.940.

"Fig. 58 is plotted from the above table. The curves show clearly how for increasing cyclic amplitudes, within the range here attempted, the effect of the same spark is increased. The curves show very distinct maxima. It is evident, moreover, that the magnitude of the effect at any point is closely connected with the slope of the hysteresis curve. On the whole the curves tend to corroborate the fact—first noted by E. Wilson in his 1902 patent specification—that the sensibility of the iron to oscillations is greatest when in the magnetic condition represented by the point of inflexion on the hysteresis curve. To examine this matter more closely these curves representing the

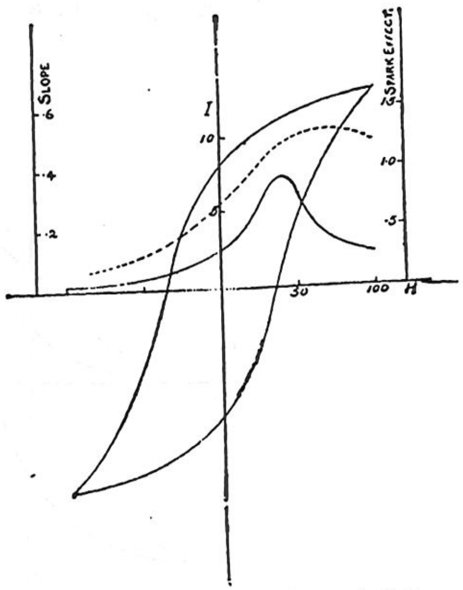


FIG. 60. The dotted curve shows spark-effect.

effect of the spark are repeated in Figs. 59, 60, 61, 62, each alongside the gradient curve, that is, first derived curve, of the corresponding cyclic curve. To assist in picturing the magnetic state of the iron, there is plotted on each diagram the proper hysteresis loop. These loops were obtained by independent experiments with the earth's field controlling the magnetometer-needle. (Reducing factor for I is 67.5.)

"In these figures the abscissæ for all the curves are milliamperes (multiply by 0.0696 to get C.G.S. field). The figures have been so constructed that, except in the cyclic curves, equal ordinates on the different figures represent absolutely equal effects. The reducing factors for the spark-effect curves are as given in connection with Table I. In all the slope curves the ordinates give at once very approximately the change of intensity of magnetisation per .001 C.G.S. increment of field. But the ordinates of

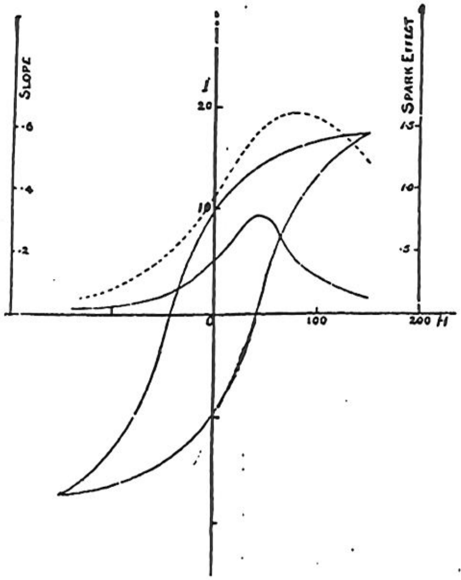


FIG. 61. The dotted curve shows spark-effect.

the cyclic curve are reduced 21 times in Fig. 59, 42 times in Fig. 60, 63 times in Fig. 61, 84 times in Fig. 62; and are thus not directly comparable with one another or with the companion curves.

"Returning to the spark-effect and the gradient curves, however, it is seen that the spark-effect is by no means a simple function of the gradient of the cyclic curve. The curves show, moreover, that the maximum effect of the spark is greater in the cycles of larger amplitude; and not only because the hysteresis curves are steeper in large cycles than in small, but also because in small cycles the effect of the oscillations is, for some unknown reason, much smaller than the diminished gradient would lead one to expect.

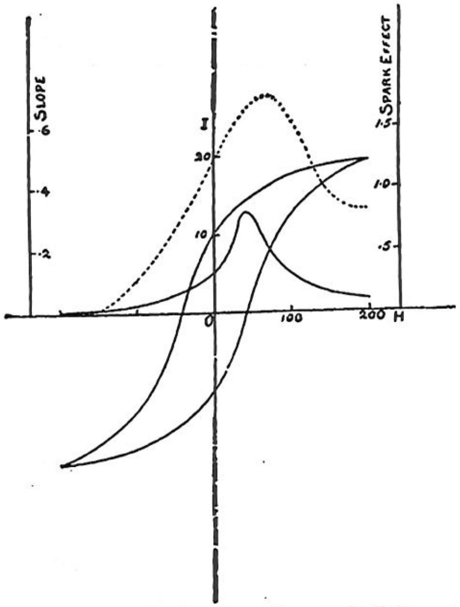


FIG. 62. The dotted curve shows spark-effect.

"It must be mentioned here that during the above measurements the effect of changing the sign of the initial charge given to the oscillation-coil was repeatedly tried. On no occasion was there any perceptible difference in the magnetometer deflexion. The damping of the oscillations must therefore have been very trifling."

Sella-Tieri Detector.—An interesting type of detector has been invented by Sella, and improved by Tieri. In the latter form it consists of a core of soft iron wires, soldered together at their ends, and placed in a glass tube rather shorter than the core. On the outside of the tube are wound coils which are connected to the aerial and earth, and to a telephone respectively. A current is passed longitudinally through the core, while at the same time it is continually twisted and untwisted by a mechanical arrangement. The core is thus circularly magnetised by the current, and under the continually varying torsion is sensitive to the oscillating longitudinal field produced by the received oscillations. The telephone indicates the sudden alterations in magnetisation which occur on the reception of a signal from the transmitter.

Heterodyne Telephone.—Fessenden invented an ingenious receiver which has proved to be very suitable for wireless telegraphy. It is a form of telephone with two windings, one of which is attached to the disc and the other fixed. The received antenna current flows in one, and in the other a local current of a frequency differing only slightly from that of the received current. The resultant action of these two is a series of beats forming a note of audible frequency in the telephone. A more complete description is given in "Wireless Telephony," by E. Ruhmer (Crosby Lockwood).

CHAPTER VI.

THERMOMETRIC DETECTORS OF OSCILLATORY CURRENTS OF HIGH FREQUENCY.

THERE are a number of instruments in use which measure the energy of the oscillatory currents in the receiving circuit, and not the voltage or current as do coherers or magnetic detectors. Their action depends on the rate at which heat is produced in a short fine wire through which the oscillatory currents of high frequency pass. (I am tired of writing this long phrase, and its equivalent for dielectric currents, viz., "a train of electric waves of high frequency." The word oscillation is used by some writers to imply high frequency oscillation only. This is unfortunate, since even *electrical* oscillations have been produced at frequencies of less than one per second. I therefore propose to adopt a good old English word which signifies a periodic motion of high frequency, to stand for "a damped train of electrical oscillations of a frequency of the same order as is employed in wireless telegraphy;" or the corresponding "oscillatory currents, voltages, or magnetic fields of high frequency," associated with them in the sending or receiving circuits of a wireless installation. The word chosen is brief and descriptive, viz., **jig.** It may be qualified where necessary to prevent confusion, thus—an *electric jig*, a *magnetic jig*, an *Irish jig*—all implying periodic motions of very high frequency. A transformer of the high frequency currents used in wireless telegraphy has been called a jigger, hence also it seems natural to call these currents "jigs.")

The energy of electric jigs, then, may be measured by their heating effect on a conductor. In some types of thermometric detector the temperature variation of the resistance of the fine wire in which the energy is converted into heat, is used as indicator; in others the heat from the wire acts on a thermo-electric junction which forms part of a galvanometer circuit. A third class, suitable for currents of some magnitude, utilises the expansion of the conductor. To the first class belong Professor Fessenden's original barreter, and Lieutenant Tissot's bolometer bridge; to the second Mr Duddell's thermo-galvanometer, and many others; and to the third that class of thermo-ammeters, whose construction is based either upon the direct elongation of a wire, as in the Cardew voltmeter, or on the untwisting of a spiral spring like the Ayrton and Perry instruments. There is also a fourth class, much used in Germany, in which the heating of the wire is measured by expansion of air in a vessel enclosing the wire.

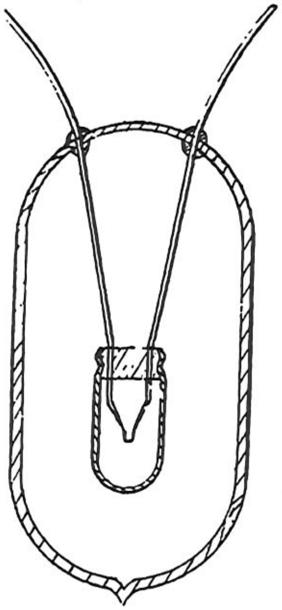


FIG. 63.—FESSENDEN'S BARRETER OR THERMAL DETECTOR.

The thermometric method is, so far, the only one which lends itself to accurate measurement of the current or energy, and as the rate of heat production is proportional to the square of the current, the thermometric detector can be easily graduated to show the R.M.S. current directly. Coherers and vacuum tubes act when the voltage rises sufficiently, magnetic detectors when the current attains a certain value, but the thermo-galvanometer indicates throughout its whole range the actual R.M.S. value of the current. In 1902 Professor Fessenden patented a form of thermal receiver which proved to be of the same order of sensibility as other wireless detectors. A short piece of extremely fine platinum wire, enclosed in a vacuum, is connected to the aerial and earth, and also forms one side of a type of Wheatstone bridge. The current jig in the receiver heats the fine wire, and as this has very small heat capacity and radiating surface, and is *in vacuo*, its temperature rises rapidly. The rise of temperature causes an increase of resistance which is indicated on the Wheatstone bridge by means of a siphon recorder or otherwise.

The system has been found to be very reliable in action, but from the fact that it depends on the energy received and not simply on the voltage or current, it is not likely to be able to compete with other forms of detector over great distances, for if the R.M.S. voltage of the jigs received falls off in proportion to the distance, the energy of the current jigs induced in the receiver will decrease in proportion to the square of the distance. As a detector, therefore, its efficiency will vary inversely as the square of the distance, instead of inversely as the distance. I understand that Professor Fessenden has now discarded this detector, at least for long-distance transmission, in favour of an electrolytic arrangement which will be described in the next chapter.

Tissot's Bolometer Bridge.—Lieutenant C. Tissot, of the French Navy, has devised a kind of bolometer for use in the measurement of the received current in wireless telegraphy, and has made many useful measurements by its means. He has kindly allowed me to quote the following from his paper communicated to the Institution of Electrical Engineers in the beginning of 1906:*—

"The principle of Langley's bolometer is well known. Two fine metal wires are inserted respectively in the two arms of a Wheatstone bridge. A variation in temperature of one of the wires produces a variation in its resistance which is indicated by the bridge galvanometer, the bridge having been previously balanced.

---

* By kind permission of the Council.

"In applying the bolometer to the detection of electric waves, it is necessary to ensure the complete heat isolation of the bolometric arms, and on the other hand to localise the action of the waves in one arm only.

"To effect this the arms, which are straight and very short—1.5 cm. of 10 μ diameter platinum wire, in the most sensitive models—are brought very near to one another within the same enclosure.

"In one of the types employed, these arms are *in vacuo.*

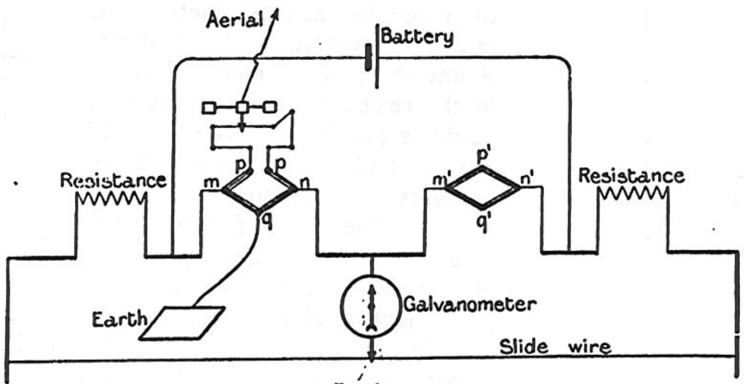


FIG. 64

The case in which they are contained is made as small as possible, and is enclosed in two successive coverings of silver-plated brass, between which is a very thin air space. The whole is immersed in a small vessel filled with water. In another model the heat isolation is obtained in a more simple manner by means of a Dewar vacuum vessel.

"According to the kind of measurements for which the apparatus is intended, two different methods are employed for localising the effect of the wave. In one of these methods, similar to that employed by Rubens, each arm of the bolometer is formed by four exactly equal pieces of wire arranged in the form of a bridge (Figs. 64 and 65).

"The balancing resistances of the bridge are either of

German silver or platinoid, and are immersed in petroleum. The balancing of the main bridge is performed by means of a slide wire of large diameter. The aerial and the earth connection are attached at p, p, and q to that diagonal which is not in the circuit of the main bridge.

"The apparatus can be calibrated direct by a continuous current, and can be used as a wattmeter (the resistance being known and the self-induction negligible). The method employed for taking the measurements consists in the observation of the permanent deflection of the galvanometer of the main bridge under the action of the waves received during a suitable time. The aerial and the earth are removed, and there is connected in their place a source of direct current capable of supplying the required current to the bolometric bridge $m\,n\,p\,q$, so as to produce the same deflection of the galvanometer of the main bridge.

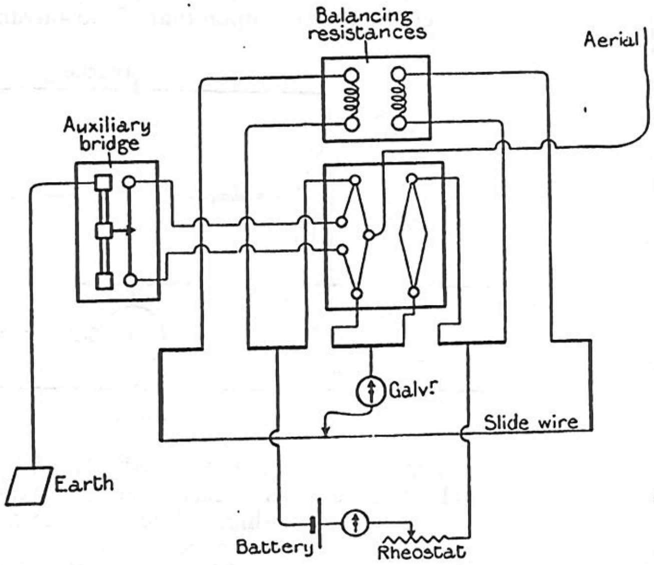


FIG. 65.

"Since it is necessary that the unbalancing of the main bridge shall be solely due to the heat developed in the auxiliary bridge *m n p q*, an external means of adjustment (a kind of slide wire) was added to the bolometric bridge in order to be able to realise exactly the desired conditions. These are obtained when the galvanometer deflects in the same direction and exactly to the same amount, on reversing the direct current in the auxiliary bridge.

"The other method of localising the effect of the waves consists in inserting between the bolometric arms, each of which are formed of a single piece of wire, suitable ironless choking coils, of dimensions previously determined by experiment. The aerial and earth are then connected as shown in Fig. 66. The sensibility of these arrangements depends, of course, upon that of the galvanometer employed.

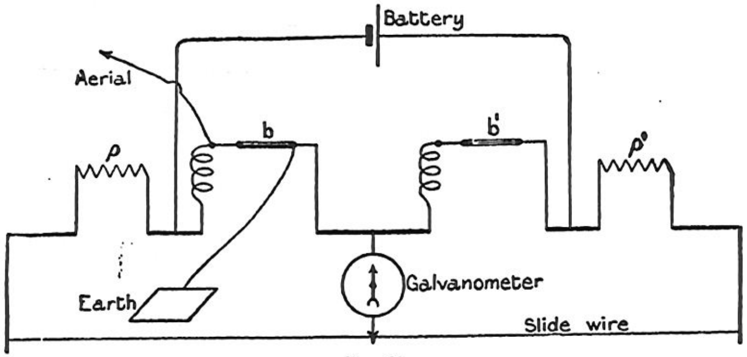


FIG. 66.

For moderate degrees of sensibility a D'Arsonval dead-beat galvanometer was used. The apparatus is then suitable for use on board ship. Where extreme sensitiveness was required I employed a moving needle galvanometer (Thomson's type) with two parallel vertical needles, the resistance of the galvanometer being chosen equal to that of each of the bridge arms. I was thus able to obtain deflections of about 10 millimetres with an effective current of 100 microamperes (scale at 1 metre distance).

"If the length of the transmitting aerial A is left constant, and that of the receiving aerial B be varied progressively, it will be noted that the deflections of the bolometer reach a maximum for a certain length of B. The aerial

systems A B are then in resonance and have the same natural period.

"When the aerials A and B have the same shape, for instance both being either simple wires, or both consisting of four parallel wires, it will be found that the resonance always occurs when the lengths are equal whatever may be the general curvature or inclination of the aerials. The measurements given refer to systems in resonance."

Professor Braun of Strasburg and other German workers have made considerable use in experimental work of a thermo-ammeter of the air-thermometer type, designed in 1827 by Mr Snow Harris. Like all other thermal instruments, it measures the steady temperature attained by the wire when heat production and radiation have reached a balance. A fine short wire is enclosed in air in the sealed end of a U-tube; a liquid is put in the lower part of the U, and the other branch is graduated. The heat expands the air, and the rise of the liquid column indicates the temperature, and therefore the current. This instrument is simple in construction, but several corrections require to be applied to the readings before the actual value of the current can be obtained. It is largely used as an indicator in the measurement of wave-length, where only *relative* values of current are required.

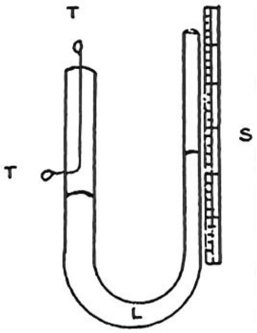


FIG. 67.—SNOW HARRIS THERMO-GALVANOMETER.

T, *T*, Terminals of fine wire; *L*, Liquid in U-tube; *S*, Scale.

Duddell's Thermo-galvanometer and Ammeter.—In order to measure the current given by a high frequency alternator, giving about 120,000 ~ per second, Mr Duddell devised a pair of instruments which between them could register through an enormous range, from about a microampere (one millionth of an ampere) up to many amperes

They are portable and easily adjusted, and are, so far, the best instruments to be had for the measurement of high frequency currents or voltages.

With Mr Duddell's kind permission,* I take the following descriptions from his paper read before the Physical Society and published in the *Philosophical Magazine*, July 1904:—

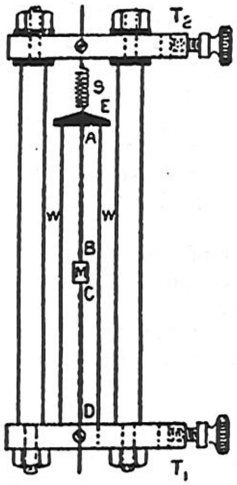


FIG. 68.

"The first instrument was designed to be very quick in action for a thermal instrument, and was made to work with a small current so that it could be used as a quick-acting voltmeter. It is essentially a very delicate Ayrton-Perry twisted strip-ammeter which has been improved by the addition of a temperature-compensation device to minimise the zero-creep when the temperature of the whole instrument changes. The working parts of the instrument are shown in Fig. 68. A B C D is the Ayrton-Perry twisted strip, of which the part A B is twisted in one direction and the part C D in the opposite. A mirror M and a very thin mica damping-vane are fixed at its centre. This strip is stretched in a frame formed of a brass block T_1 carrying one terminal and a piece of ebonite E, the sides of the frame being formed of wires W W. This frame itself is stretched by means of a spiral spring S fixed to the other terminal block T_2.

"The twisted strip A B C D and the wires W W are made of the same metal; in fact, the strip A B C D is actually flatted from the wire W W, so that the twisted strip and wires have the same temperature-coefficient of expansion. If the wires and strip rise in temperature equally, then the whole frame E W T_1 W simply gets longer and no twist of the mirror ensues. If, however, a current be sent from T_1 to T_2 through the strip, then it heats and twists up, rotating the mirror M. Owing to the fineness of the strip (0.001" PtAg) which is heated by the current, the instrument is very quick in action. The mechanical periodic time is also very short, about $\frac{1}{16}$ second; so that it is able to follow with a fair accuracy currents which vary over a small range as rapidly as one or two cycles per second.

"The data of this actual instrument are:—Resistance, 20 ohms; current to give 25 cm. at 100 cm. scale-distance, 22×10^{-3} ampere; P.D. to give 25 cm. at 100 cm. scale-distance, 0.44 volt.

"So that taking 1 cm. as the smallest measurable deflexion and 0.1 mm. as the smallest detectable movement—

The smallest measurable current is 4.4×10^{-3} ampere.
" detectable " 0.5×10^{-3} ampere.
Watts required to produce smallest measurable deflexion, *i.e.*, 1 cm., 387 micro-watts.

"It is evident that this very simple instrument has many uses. It is very easily set up, requiring no careful levelling, and is quite robust. The present instrument which I made three years ago has often been carried about just as it is in the pocket. The self-induction of the wire is extremely small, and the temperature-coefficient of the resistance of the wire (PtAg) is small also; so that the instrument can be used as a voltmeter to measure voltages down to about 0.1 volt, and I have used it in series with high resistances to measure voltages up to 10,000 volts. The instrument can of course be shunted to measure large currents; but if a good deflexion of say 25 cm. is required, the drop in volts on the shunt, 0.44 volt, is serious. Its main defect is that it requires screening from quick vibrations of the order of $\frac{1}{16}$ second, as the damping is not quite sufficient. I find that this can be easily done by standing the instrument on a heavy block which is suspended by means of wires and springs as in the Julius suspension for galvanometers.

"The second instrument is much more delicate and sensitive. It was made primarily to measure very small voltages and currents even with very high frequencies up to 120,000 ~ per second. At this high frequency the alternator I made would only give an extremely small output; it was therefore necessary, in order to carry out the experiment, to reduce the power required to work the instrument to its lowest possible value. I have called this instrument a Thermo-galvanometer.

---

* By kind consent of the publishers.

"The principle of the thermo-galvanometer is quite simple. It consists of a resistance which is heated by the passage of the current to be measured, and the radiant heat from which falls on the thermojunction of a Boys radio-micrometer.* As at first constructed, it consisted of a heating resistance made of three or four turns of 0.001 inch diameter platinum-silver wire wound on a piece of mica, and placed as close as possible to the radiation receiving-plate of an ordinary Boys radio-micrometer, made by the Cambridge Scientific Instrument Company. This instrument was sensitive but exceedingly slow in action, taking over a minute to approximately attain the deflexion corresponding with the current flowing.

"A new radio-micrometer was therefore constructed following the instructions given in Professor Boys' paper, but having a very much smaller suspended loop than the radio-micrometer as usually constructed. The radiation receiving-plate was also omitted in order to reduce the quantity of metal to be heated, and the heating resistance was placed directly underneath the lower thermojunction, so that the junction received heat from it both by radiation and convection. The arrangement of the instrument is shown diagrammatically in Fig. 69.

"In the field between the pole-pieces N S (Fig. 69) of a permanent magnet is suspended by means of a quartz fibre a single-turn coil or loop of wire *l*, to the lower ends of which is fixed the thermocouple Bi, Sb. This loop is surmounted by a glass stem *g* and a mirror M. Below the lower junction of the thermocouple is fixed the heating resistance *h*, one end of which was connected to the frame of the instrument to avoid electrostatic forces. The action of the instrument is as follows. The current to be measured flows through *h* and raises its temperature, causing the lower junction of the thermocouple to rise in temperature above the upper, thus producing a current round the loop, which is deflected by the magnetic field against the torsion of the quartz fibre.

---

* *Philosophical Transactions of R.S.* 1889, vol. clxxx. p. 159.

"The data of the instrument are:—Resistance, 18 ohms; current to give 25 cm. at 100 cm. scale distance, 8×10^{-4} ampere; P.D. to give 25 cm. at 100 cm. scale-distance, 14.4×10^{-3} volt.

"So that, taking as before 1 cm. as the smallest measurable and 0.1 mm. as the smallest detectable deflexion, the smallest measurable current is 1.6×10^{-4} ampere; the smallest detectable current is 0.2×10^{-4} ampere; watts required to produce smallest measurable deflexion, 0.46 microwatt.

"The deflexions of the instrument were nearly proportional to the square of the current; assuming the instrument correct at 100 divisions deflexion, then higher deflexions required to be increased by amounts gradually increasing up to between 4 and 5 divisions at a deflexion of 400 divisions, in order that the corrected deflexion might be accurately proportional to the square of the current flowing.

"To give an idea of the time the instrument requires to take up the permanent deflexion corresponding with any current, Table I. is given below of the deflexions at different times after starting a current of 8×10^{-4} ampere; and after interrupting the same, to show the time required for the instrument to return to zero. From which it will be seen that the instrument attains after 10 seconds its full deflexion to within 1 part

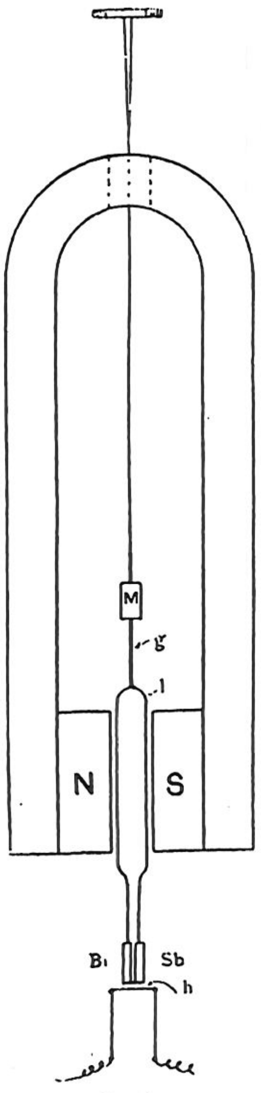


Fig. 69.

in 500, or as it is a square law instrument indicates the true current to within 0.1 per cent.

"TABLE I.

Time in Seconds after Starting a Current of 8×10^{-4} Ampere.	Deflexion in Scale-divisions.	Time in Seconds after Interrupting the Current.	Deflexion in Scale-divisions.
5	500.5	5	1.5
10	501.0	10	1.0
30	501.5	30	0.5
60	502.0	60	0
120	502.0	120	0
180	502.0	180	0

"TABLE II.

For deflexion of 25 cm. at 100 cm. scale-distance.

Instrument.	Resistance in Ohms.	Current in Micro-amperes.	P.D. in Milli-volts.	Power in Micro-watts.
Thermo-galvanometer, gold heater - -	18	800	14.4	11.5
Thermo-galvanometer, platinum on glass heater - - -	103	346	35.6	12.3
Do. do. -	202.5	275	55.6	15.3
Do. do. -	363	231	84	19.4
Do. do. -	1,071	121	130	15.7
Do. do. -	3,367	88	296	26.0
Do. do. -	13,910	31	431	13.9
Ayrton-Perry twisted strip - - -	20	22,000	440	9,680

"This instrument, which forms practically a sensitive alternate-current galvanometer, worked very satisfactorily, even with the highest frequencies used of 120,000 ~ per second. As examples of its sensibility, it may be mentioned that on making a suitable noise into a Bell *telephone-receiver* sufficient current is generated to send the spot off the scale; and that if the thermo-galvanometer be connected to the line wires of a *microphone-transmitter* arranged in the ordinary way, whistling at a distance of from 15 to 20 feet from the microphone will cause deflections of the instrument of several hundred scale-divisions.

"A set of high-resistance heaters have been made and put in the above thermo-galvanometer, and the results obtained are given in Table II. The currents, P.D.s, and power are those required to give a deflection ¼ the scale-distance, which forms a very convenient basis on which to compare square law instruments. I have also included the Ayrton-Perry twisted strip instrument in the table for comparison."

The last class of thermal detectors or ammeters, which depend on the expansion of the heated wire itself, are so simple in construction and so like instruments that are already well known to electricians, that it is unnecessary to describe them here. They are not sufficiently sensitive to serve the purpose of detectors in long-distance transmission. The Duddell thermo-galvanometer, on the other hand, though somewhat slow in action, is comparable in sensibility with the coherer, and can be used in telegraphy over considerable distances. As the readings of a thermal instrument are proportional to the squares of the currents, it is clear that it is much more sensitive in the upper part of its scale than in the lower.

On the whole, hot-wire detectors are not much used for actual telegraphic work, but almost all the measurements of the electrical energy concerned in the different processes of wireless telegraphy have been made by their aid.

At the American Association for the Advancement of Science in 1899, Professor Fessenden described a current measuring instrument on the same principle as the Duddell thermo-galvanometer.

Crystalline Rectifiers.—The members of a large class of detectors, recently found, depend for their action on the rectifying and thermo-electric qualities of various crystals. Among others may be mentioned, carborundum, silicon, molybdenite, galena. These may be used without any local battery, though in many cases a small additional voltage is advantageous. The action of these detectors depends on thermo-electric phenomena at the contact between the crystal and metal; it therefore resembles coherence in being a surface phenomenon.

This conclusion is borne out by the experiments of Pierce on carborundum, and Austin on silicon. Pierce showed that in the case of a crystal of carborundum platinised on one side only the ratio of rectification, *i.e.*, of the current in one direction to that in the reverse under the same voltage, may be as high as 1000 : 1; but that if both sides be platinised the ratio did not exceed 1.66 : 1. The provision of a larger surface of metallic contact thus reduces the ratio enormously. Austin in an exhaustive examination of the silicon detector comes to the conclusion that its action is mainly a contact phenomenon.

A considerable amount of material as to the behaviour of crystalline detectors and other types of self-restoring coherers has been published during 1909 and 1910. Among the more important researches are those of Pierce,* Torikata,† Eccles,‡ and Austin.§ The first has given many curves showing the rectifying properties of iron pyrites, molybdenite, and other materials when in contact with steel, aluminium, and other substances; the second a long list of materials tested for their properties as detectors with notes on their sensibility, and diagrams of their current-voltage curves; the third has approached the subject with the object of elucidating the theory of action of detectors in general. As Dr Eccles'

---

* *Electrician*, Feb. 11, 1910.

† *Electrician*, Sept. 16, 1910.

‡ *Phys. Soc. Proc.* 1910, or *Electrician*, Aug. 12, 19, and 26, 1910, and Nov. 11, 1910.

§ *Bull. Bureau of Standards*, vol. vi., No. 4, 1910.

results throw a great deal of light on the behaviour of some of the more useful types of detector, I shall give a short abstract of them. In a paper read before the Physical Society of London in March 1910, a study is made of an iron oxide detector consisting of a steel needle slightly oxidised by annealing, and an iron plate or a drop of mercury. It was found that the action of this detector could be explained by the change of resistance consequent upon the rise of temperature caused by the passage of the high frequency received current through the film of oxide. The temperature variation of the resistance of the oxide is a large one, viz.: a decrease of about 1 per cent. per degree centigrade rise of temperature, hence the passage of even a very small current through the minute mass of oxide at the point of contact is sufficient to disturb the equilibrium of the direct current from the

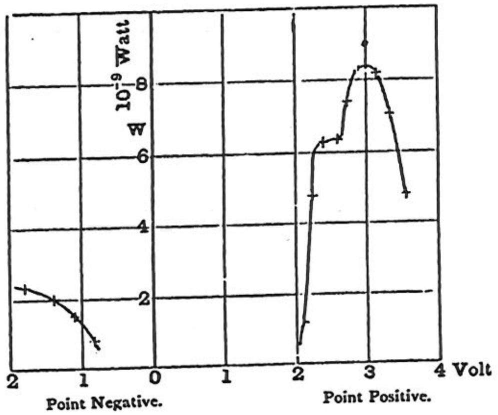


FIG. 70.—ELECTROLYTIC DETECTOR, SENSITIVENESS CURVE. [ECCLES.]

$W = 6.2 \times 10^{-8}$ WATT.

This detector consisted of two platinum electrodes in dilute sulphuric acid (one of acid to four of water). One electrode was a platinum wire of 0.0006 cm. diameter drawn by the Wollaston process, dipping a fraction of a millimetre into the electrolyte; the other was a piece of thick wire well immersed. W is power of h.f. current put in, and w power delivered to telephone.

local battery in circuit. Since the resistance falls, the local current rises and actuates the telephone diaphragm. The fact that the temperature variation of the resistance is negative, *i.e.*, a decrease with rising temperature, ensures that the increase of the local current is somewhat prolonged, and therefore more easily affects the telephone. The paper contains not only experimental results but a mathematical discussion of the problem, leading the writer to the conclusion that the whole of the results could be explained on the assumption that the only electrical phenomena involved are the Joule effect (*i.e.*, heating proportional to C^2R) and the temperature variation of the resistance of the oxide between the metal electrodes.

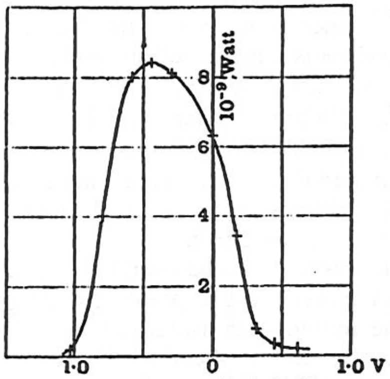


FIG. 71.—ZINCITE-CHALCOPYRITE OR "PERICON" DETECTOR, SENSITIVENESS CURVE. [ECCLES.]

$W = 6.2 \times 10^{-8}$ WATT.

(A fragment of Native Brown Oxide of Zinc and piece of Iron, Copper, Sulphide.)

Dr Eccles next tested his theory by constructing a detector from two similar pieces of the same material (galena), this material being one having a large negative temperature variation of resistance. The measurements with this detector confirmed the theory, and in addition showed the detector to be a sensitive and satisfactory one when the proper local voltage was applied. As a matter of fact, this galena-galena detector had already been patented in the Commonwealth of Australia by Mr Henry Sutton in March 1910, who believes that it acts partly by reduction of resistance of the contact on account of the increased pressure due to the expansion of the heated points.*

---

* *Electrician*, Dec. 16, 1910.

In the case of rectifying detectors which act without any applied local voltage, Dr Eccles suggests that the phenomena may be explained by the combination of the Joule and Peltier effects; a suggestion which is supported by the following short analysis of the action which I have made.

Action of Rectifiers.—Peltier discovered that if a steady current be passed from one conductor to another of a different material the temperature of the junction is raised if the current be in one direction, and lowered if it be in the other direction, *i.e.*, heat is created or destroyed in accordance with the direction and amount of the current. Now let us suppose, as is the case in detectors of this type, that one or both of the substances has a large temperature variation of resistance. Suppose that an alternating voltage, such as is received from the aerial wire at a receiving station, is applied to the detector, then, when the current is flowing in one direction, the temperature of the junction will rise owing to (1) Joulean production (C^2R), and (2) owing to the Peltier effect. The effect will be a large diminution of the resistance, and a large current will result. Since we suppose the resistance to decrease with increase of temperature a species

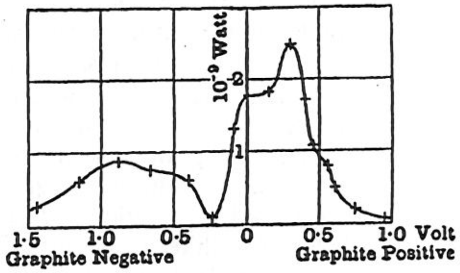


FIG. 72.—GALENA-GRAPHITE DETECTOR, SENSITIVENESS CURVE. [ECCLES.]

$W = 7.8 \times 10^{-8}$ WATT.

of regenerative action will go on, every increase of current increasing both the Peltier production of heat and the conductivity of the junction. A large current, therefore, passes in this direction under the influence of the applied voltage. When the voltage is reversed, however, during the second half of the cycle, the conditions are different. The Peltier effect for a current in this direction is cooling, and the greater the current the greater the cooling. Instead, therefore, of a great reduction of resistance due to the cumulative effect of Peltier and Joulean heat we find the rise of temperature due to the latter checked by the Peltier cooling, and the resistance remains high. With voltage in this direction, therefore, the current is very small as compared with that in the other. Thus on the whole the current is "rectified" and will affect a telephone.

The diagrams, Figs. 70, 71, and 72, which I take from Dr Eccles' paper, give some interesting practical details of the sensibility of the various detectors. I may add that on calculating the maximum values of their efficiencies from the data of the diagrams I find that they are as follows:—Electrolytic $\eta = 13.2$ p.c.; Zincite $\eta = 13.4$ p.c.; Galena-Graphite $\eta = 3.2$ p.c. The low electrical efficiency of the last is, however, to some extent compensated by its reliability and insensitiveness to mechanical vibration. These efficiencies are practically constant for a considerable variation of the power supplied, as is shown by other diagrams which there is not space for here.

Note 1.—Austin found that the Fleming valve had, with $\lambda = 350$ m., only one half, and at $\lambda = 900$ m., only one tenth of the sensitiveness of the perikon. The smallness of the latter figure he attributes to the fact that the coupling in the apparatus supplied was fixed at an unsuitable value. He found that De Forest's Audion was one and a half times as sensitive as an electrolytic, *i.e.*, nearly three times as sensitive as the perikon.

Note 2.—Eccles has developed the above explanation of the action of rectifiers in a paper read before the Physical Society of London during this year (1913).

CHAPTER VII.

ELECTROLYTIC DETECTORS.

Electrolytic detectors may be divided into two chief classes, both of which are in very common use in wireless telegraphy. The first class is a type of anti-coherer; *i.e.*, the resistance is increased by the action of the jigs; the second class is a species of intermittent electric valve, whose action resembles very closely that of the Wehnelt interrupter. Theory lags far behind practice in these matters, so the first thing to be done is obviously to give an unexplained description of the actual instruments. Of the first class the detector of Dr Lee de Forest is one of the best and most sensitive.

It consists of a tube containing two metallic electrodes, with an electrolysable paste of litharge with glycerine or vaseline mixed with water or alcohol, and a few metal filings. On the application of a continuous E.M.F., from a local battery, in series with a resistance of 30,000 or 40,000 ohms, a small continuous current passes through the paste, forming in it the fine crystalline structures usually called "lead trees." The aerial and earth wires are also attached to the terminals of the detector. On arrival of an electric jig the resistance momentarily increases, and the sudden change of current resulting is observed as a click in a telephone receiver in the local circuit.

From microscopic observations, Dr de Forest discovered that the treelike crystals, which are formed by electrolysis from various metallic solutions, are broken up by the action of current jigs, but are immediately reformed by the current from the local battery. It seems probable that the tips of the lead trees are melted or deflagrated by the oscillatory currents. The leaves of the trees are extremely thin plates, coming to very sharp points; as therefore the resistance must be almost entirely localised at the tips of the leaves, a very moderate amount of current will be sufficient to fuse them and make the circuit discontinuous. The rapidity with which the circuit recovers continuity proves that the breaks in it must be very minute, the crystals growing again immediately under the influence of the constant voltage applied by the local battery. This detector has been found to be exceedingly sensitive and quite reliable.

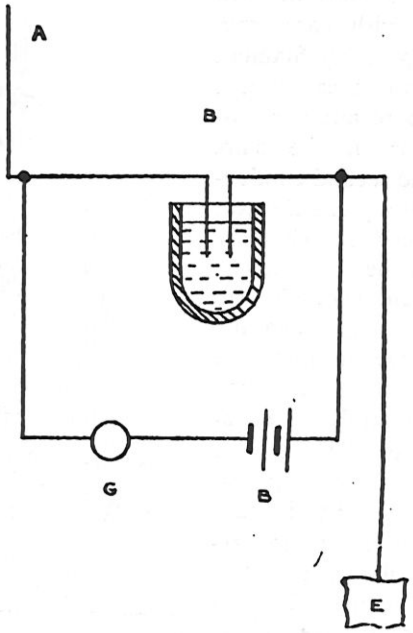


FIG. 73.—PUPIN'S ELECTROLYTIC RECEIVER.
A, Aerial; *B*, Detector; *E*, Earth; *B*, Battery; *G*, Galvanometer or Telephone.

The second principal type of electrolytic detector has only a liquid between the electrodes, one at least of which must be very small. The best electrolyte for signalling purposes appears to be nitric acid. A battery and a telephone receiver are put in series with the detector. If the terminals of the detector are also connected to air and earth wires, signals may be received as with other forms of detector. The invention appears to be due to M. J. Pupin; U.S. patent 713,045 of 4/1/98.

The thing is practically a small Wehnelt interrupter, in which the applied voltage of the battery is too small to maintain an appreciable current without the assistance of the electric jigs. A Wehnelt break will not start work unless there is a certain minimum inductance in circuit. This condition means that the break will not start unless the electricity is surging to and fro, since the effect of putting inductance in a circuit is to make such revibration possible. Under these conditions quiet electrolysis of the liquid gives place to a much larger but intermittent current, suitable for use in the primary of an induction coil. Perhaps the theory which best suits both cases is, that the surges destroy the "polarisation" of the cell, and thus allow a sudden rush of current from the battery which shortly fails again owing to reformation of the film which constitutes "polarisation." The sudden stoppage produces again electrical surges in the circuit if the total resistance be low, as in the Wehnelt break, which again destroy the polarisation. In the detector, or barreter, as Professor Fessenden calls it, the applied voltage is not high enough to keep up the intermittent current by causing surges in the circuit when it stops and starts, the current therefore only flows when surges are impressed upon it by an outside agency, *i.e.*, the jigs transmitted to the detector by the aerial and earth wires.

There has been considerable difference of opinion as to the mode of action of these detectors, Professor Fessenden holding that it is due to variation of the resistance of the electrolyte through heating by the current, while others speak of "polarisation" as the only cause. One difficulty in deciding between the claims of the rival theories is the vagueness of the knowledge which we have of the actual mechanism of polarisation; also it must be observed that a thin film of vapour produced by heat, and not electrolysis, would appear to be equally effective in increasing the resistance, and may account for the action of the Wehnelt break. It seems possible that the actual molecular process in the barreter may be otherwise explained by taking into account

Dr H. S. Sand's observations on the rapid increase of resistance which takes place at an electrode very shortly after a direct current is started in an electrolyte. Dr Sand* has shown that even in a cell in which polarisation does not, under ordinary conditions, occur, the resistance of the layer of electrolyte nearest to the electrode is much less at the commencement than it is when a steady state has been attained, and he has proved that this rise of resistance is due to the layer next the electrode becoming partially depleted of the ions which were in it before the E.M.F. was applied. In the barreter this action must be superposed on any others which are taking place, and may be the most important of them all. The jig voltage, by creating ions, may cause increased conductivity, which is immediately lost by continued application of the steady voltage of the local circuit. It is thus possible that the phenomenon may be explainable without reference to films of gas or even temperature variations of resistance.

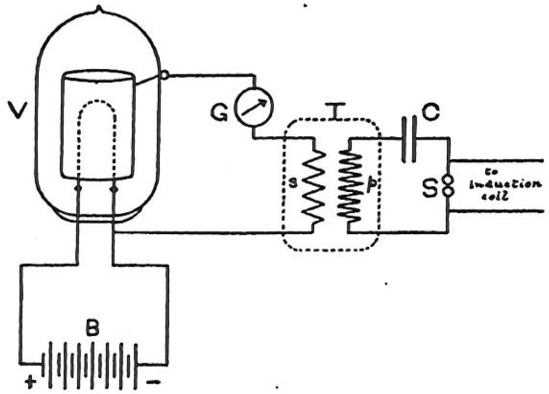


FIG. 74.—VACUUM VALVE USED TO RECTIFY ELECTRIC OSCILLATIONS AND RENDER THEM DETECTABLE BY AN ORDINARY GALVANOMETER, *G*.

(From "Electric Wave Telegraphy," by kind permission of Prof. Fleming and Messrs Longmans, Green, & Co.)

---

* *Proc. Faraday Soc.* vol. i. p. 1, 1904.

This type of detector is very sensitive, and is in use in many wireless telegraph stations in all parts of the world.

Fleming's Hot Carbon Rectifier.—Professor Fleming discovered in 1890 that a current will pass with ease from the glowing filament of an incandescent lamp to another conductor in the bulb. If the second conductor be a piece of metal the current will pass from the metal to the carbon through the space only when the positive terminal is connected to the metal and the negative terminal of the cell to the negative end of the battery which heats the carbon filament. The arrangement is thus a rectifier, *i.e.*, if an alternating voltage be applied to the terminals, an intermittent current in one direction only will be transmitted. The apparatus may be used to detect oscillatory currents by means of an ordinary galvanometer, as under favourable circum-

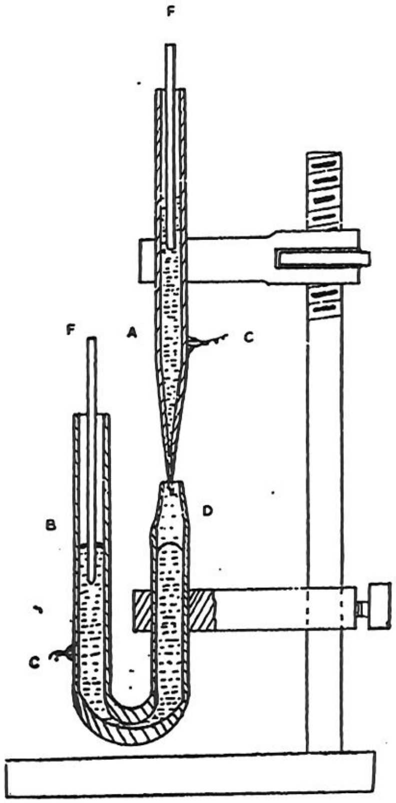


FIG. 75.—ORLING AND ARMSTRONG CAPILLARY RECEIVER:—ADAPTED FORM OF LIPPMANN'S ELECTROMETER.

A, Glass tube ending in fine point, filled with mercury; *B*, U-tube with mercury:—dilute acid at *D*; *C*, *C*, Platinum wires connecting mercury with aerial and earth; *F*, *F*, rods for regulating mercury level.

stances, *e.g.*, when the carbon filament is giving light at the rate of about one candle per three watts and the metal conductor is cool, the rectification is stated to be from 80 to 85 per cent.

Dr de Forest has improved this detector by the addition of a separate and higher source of voltage between the filament and sheath, and by the addition of a second cool electrode. The instrument is called the Audion. It is not a simple valve, but has a trigger or relay action, rendering it more sensitive than Fleming's device.

Armstrong and Orling Electro-capillary Detectors.—Messrs Armstrong and Orling have shown that a capillary electrometer of Lippmann's invention may be used as a detector of jigs. A glass tube, drawn down to a very fine bore at one end, dips into a wider tube. Mercury is put in the wide tube with dilute sulphuric acid on top of it. Mercury is also put in the upper and wider end of the fine tube, but does not run out at the bottom because of its surface tension. The lower end of this tube dips into the sulphuric acid in the wide tube, and by forcing the mercury down the upper tube and allowing it to retract, the air in the upper tube is driven out and the acid electrolyte becomes continuous between the mercury electrodes. Very minute changes of voltage will cause an alteration of the surface tension of the mercury, and produce a motion of the column in the fine tube, which is easily observable by means of a magnifying glass, and may be recorded photographically or otherwise.

I have included the above descriptions in order to show by what a large variety of means it is possible to detect electric jigs. Success in wireless telegraphy, then, depends much more on the proper adaptation of the detector, of whatever kind it may be, to the rest of the apparatus, than on the actual species of detector used.

CHAPTER VIII.

*THE MARCONI SYSTEM.**

THE LODGE-MUIRHEAD SYSTEM.

MR MARCONI has always been foremost in long-distance transmission. The first great step was in December 1901 when he received signals in Newfoundland from Poldhu in Cornwall, *during the day time.* This, as subsequent discoveries have proved, was a very remarkable feat. No other experimenter succeeded in detecting electro-magnetic wave signals across the Atlantic until 1905, and then only by night. In February 1902 Marconi made his discovery of the difference between day and night transmission when on an experimental voyage in the S.S. "Philadelphia," during which signals were received up to a distance of over 2,000 miles (see Chapter XVI.). In the same year a complete station was erected at Glace Bay, Cape Breton, which was for some time in communication with Poldhu, 2,600 statute miles away. Messages were also transmitted from the station erected earlier at Cape Cod, Massachusetts, to Poldhu in 1903, a distance of over 3,000 miles, this being the greatest range attained at that date. Other long-distance experiments were made between the "Carlo Alberto," of the Italian Navy, and Poldhu, in which case the distance achieved was more than 1,000 miles mainly overland. In consequence of the knowledge gained in these and other experiments Mr Marconi erected a large station at Clifden in Co. Galway and increased the power at Glace Bay until, in October 1907, he was able to initiate a regular telegraphic service across the Atlantic. Since then several million words have been transmitted and paid for, in addition, of course, to a large number of service messages and experimental work.

---

* The Goldschmidt System has also been bought by the Marconi Company (October 1913).

In these transatlantic stations Mr Marconi uses his new generator of high frequency currents, described below, and many modifications have had to be made in the original plans of the apparatus owing to unforeseen difficulties occurring through the great power used; these

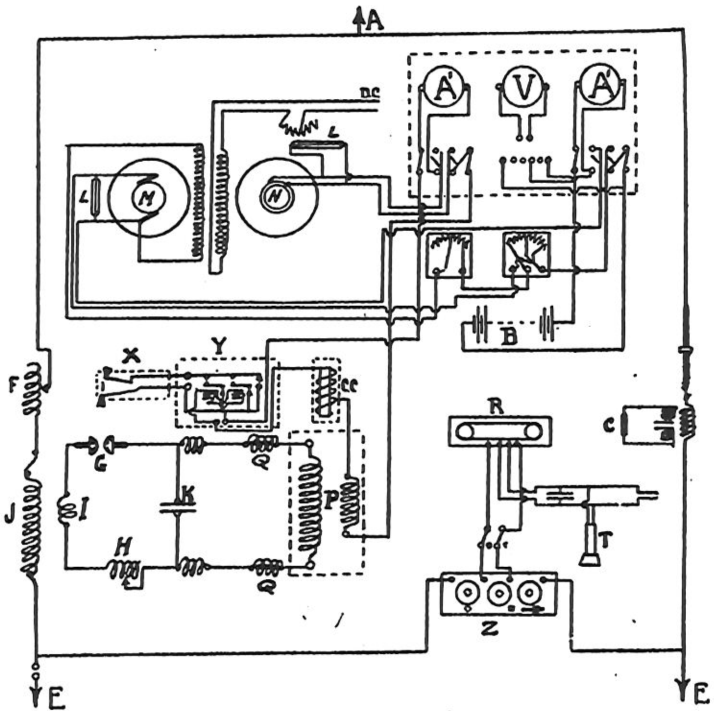
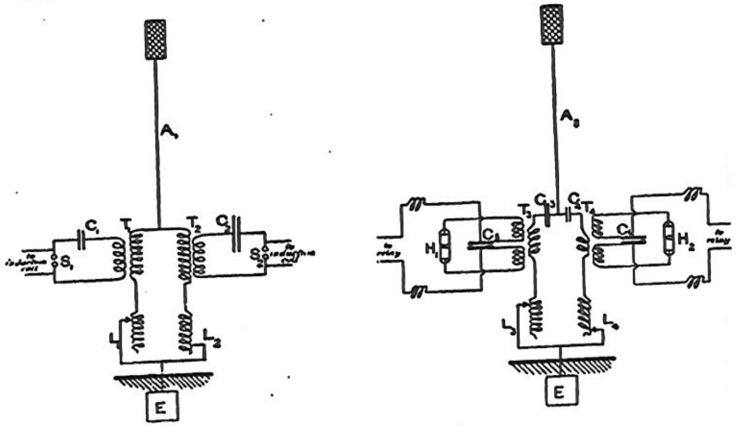


FIG. 76.—A MODERN MARCONI STATION.

A, Aerial; *A′*, Ammeters; *B*, Battery of 52 Cells; *C*, Coherer Receiver for Call Bell; *CC*, Choking Coil, adjustable, on Main Power Circuit; *E*, Earth; *F*, Tuning Inductance; *G*, Spark-Gap; *H*, Tuning Inductance; *I*, Primary of Coupling; *J*, Secondary of Coupling; *K*, Condensers; *L*, Lamps to damp Oscillations in Motor, &c.; *M*, D.C. Motor, or Dynamo for Charging; *N*, Alternator coupled to Motor; *P*, Main Transformer; *QQ*, Chokers; *R*, Magnetic Detector: *T*, Telephone; *V*, Voltmeter; *X*, Sending Key actuating *Y*, a form of Gray's A.C. Key; *Z*, Tuner.

difficulties have, however, been to a great extent overcome by patient experiment, and the service is now carried on with a regularity which is remarkable considering the short time it has been in operation.

The more important improvements embodied in modern installations are (1) the receiving transformer, or jigger; (2) the adoption of coupled circuits for producing long trains of oscillations of high frequency and voltage; and (3) the magnetic detector. Other improvements consist in the use of uniform H.F. alternating current, produced by the generator described on pp. 145 *et seq.*, and in various combinations of inductances and capacities for the purpose of rendering the receiver responsive to jigs of a definite frequency only. Many difficulties occurred on account of the enormous power of the spark in a large station, for though the total amount of energy sent out at each spark may be comparatively small, perhaps only a few foot-pounds, the time is so short that the activity during the existence of the spark is very great. In a small station which sends out about one foot-pound of energy per spark,



Transmitting Station. Receiving Station.

FIG. 77.—ARRANGEMENT OF TRANSMITTING AND RECEIVING APPARATUS IN MARCONI SYSTEM OF DIPLEX WIRELESS TELEGRAPHY.

the horse-power during the spark is about 300; in a larger station it is proportionately greater, probably amounting to tens, or even hundreds, of thousands of horse-power. This high rate of working, though only momentary, requires that conductors and insulators alike should be of special designs best suited to the new conditions. The determination of the proper forms for the multifarious apparatus necessary has been a cause of delay in the completion of some of the larger stations to an extent which was not foreseen. The preliminary difficulties have, however, been got over satisfactorily, and for some time past the transmission of messages over distances of at least two thousand miles has been carried on with regularity. Fig. 76 shows diagrammatically the arrangement of a modern station on the Marconi system.

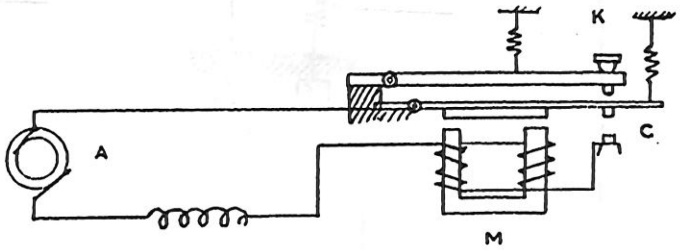


FIG. 78.—GRAY'S SENDING KEY FOR ALTERNATOR CIRCUIT (Marconi Company Patent). *A*, Alternator; *M*, Electro-magnet; *C*, Circuit-making Contacts; *K*, Handle of Key. The contact *C* is only broken by the action of the spring at the moment when the magnetic attraction of *M*, and therefore the main current, is zero, thus avoiding arcing.

Among other details of the apparatus an important one is the sending key patented by the Marconi Company, in conjunction with Mr Andrew Gray. In dealing with the large alternating currents in use at the larger stations it was clearly impossible to use an ordinary Morse key for transmitting on account of the arc which may be formed between the contacts. To obviate this difficulty the key shown in Fig. 78 was designed. It is constructed so as to allow of the contact being broken only at a moment when the instantaneous value of the current is zero. As this occurs perhaps a hundred times every second the actual break does not lag appreciably behind the movement of the handle by the operator. The contacts are held together by an electro-magnet actuated by the alternating current, and therefore are only free to separate at the moment when the value of the current is zero, which happens twice during every alternation.

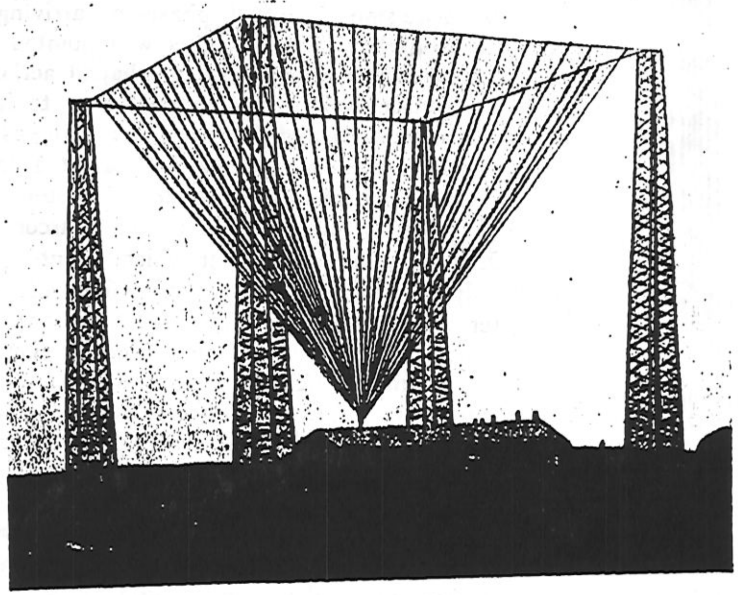


FIG. 79.—MARCONI STATION AT GLACE BAY.
The aerial has recently been altered to the directive form.

The spark itself was at first the cause of much trouble in high power stations, the great heat generated producing pits in the metal of the discharging balls at the point where a spark took place. The deafening rattle of the discharge was also very trying to the operators. These difficulties, however, do not occur with the uniform current generator now used in the transatlantic stations.

The outside gear at a large station is shown in Fig. 79. The pyramidal aerial depicted, though of large capacity and convenient shape, has the disadvantage that the waves from one side interfere to some extent with those from the opposite side, since their phases on arriving at the receiver are slightly different. This was pointed out by Dr de Forest, who found that a fan-shaped aerial radiates much more strongly in a line perpendicular to its plane than in the plane itself, and that the same is true as regards absorption of jigs by a fan-shaped aerial at a receiving station. We shall return to this matter in Chapter XIV.

Another improvement in the Marconi system is the X-stopper, an instrument which is intended to transmit only jigs of a definite frequency from the aerial and earth terminals of the receiver to the detector. This is accomplished by making two earth connections to the aerial. One of these, which contains much capacity and inductance, and has therefore a definite frequency of vibration, is the receiver circuit; the other earth wire has very little capacity or inductance, and will therefore conduct jigs of any period as forced vibrations, and is connected to a point on the main circuit which is a node for the proper vibration. Hence it does not take energy from the receiving circuit. If jigs having the proper frequency are received on the earth and aerial wires, they cause the receiver circuit to revibrate, and are recorded in the instruments; if disturbances of any other frequency arrive they do not go through the receiver circuit, but pass between the earth and aerial by the second wire whose electrical inertia is so much smaller.

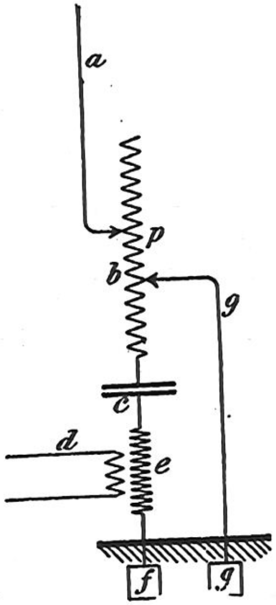


FIG. 80.

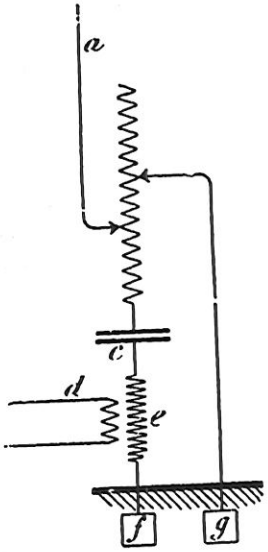


FIG. 81.

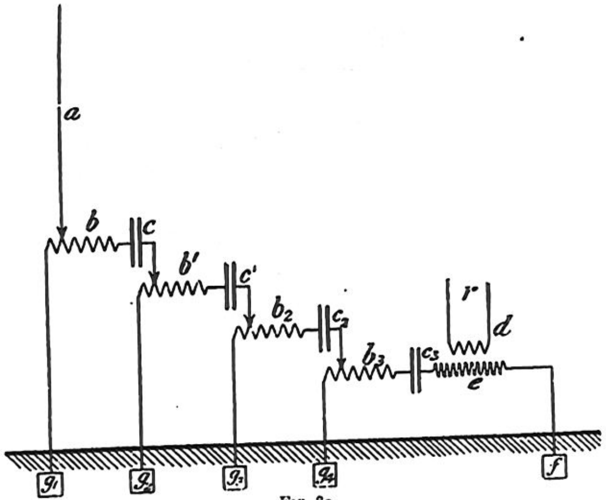


FIG. 82.

DIAGRAM SHOWING THE CONNECTIONS IN MARCONI'S X-STOPPER.
a, Receiving Antenna; *p*, Inductance Coil with Sliding Contact, *b*; *c*, Condenser; *e*, *d*, Jigger in Cymoscope; *f*, *g*, Earth-Plates.

The best results are obtainable by using a number of the capacity and inductance vibrators in series, each with its proper earth wire, the receiver being on the last vibrator, as in Fig. 82.

The X-stopper (which means the stopper of stray waves or X's) should be compared with Slaby's aerial and syntonic horizontal wire with two earth-plates, which it resembles. Other arrangements of capacities and inductances for a similar purpose have been patented by Professor Fessenden and almost every inventor in wireless telegraphy.

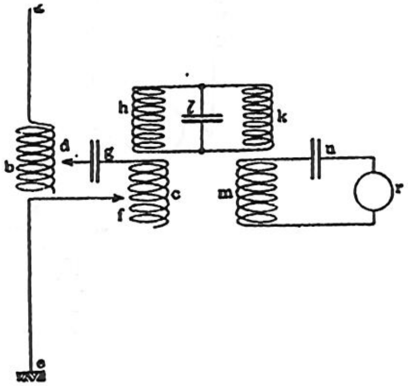


FIG. 83.—MARCONI TUNER FOR RECEIVING STATION.
a, Aerial; *b*, Aerial Inductance; *g*, Main Condenser; *h*, *l*, *k*, Intermediate Circuit; *m*, *n*, *r*, Detector Circuit.

The Tuner.—Another instrument for a somewhat similar purpose has been designed quite recently (1908). It is called the tuner and contains the inductances, capacities, and coupling arrangements required in a tuned receiving station. The whole is included in a case little over a foot long, and on the outside of which are dials indicating wave-lengths and other measurable quantities such as inductance and coupling directly. The internal arrangements are shown diagrammatically in Fig. 83.

The following quotation from a lecture delivered by Mr Marconi to the Royal Institution on 13th March 1908 gives a very succinct description of recent developments in long-distance telegraphy. I have appended to it my explanation of the action of his new generator:—

"Early in 1905, the construction of the new station at Glace Bay was sufficiently advanced to allow of preliminary tests being carried out. The aerial was very large, and consisted of a vertical portion in the middle 220 feet long supported by four towers and attached to horizontal wires, 200 in number, each 1,000 feet long extending radially all round, and supported at a height of 180 feet from the ground by an inner circle of eight and an outer circle of sixteen masts (Fig. 84).

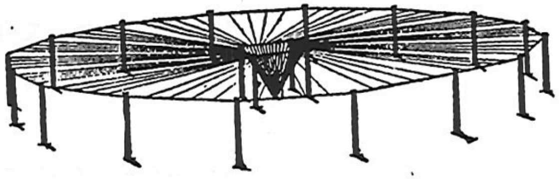


FIG. 84.—GLACE BAY AERIAL, EARLY FORM.

"The natural period of oscillation of this aerial gave a wave-length of 12,000 feet.

"The capacity employed was 1.8 microfarads, and the spark length $\frac{3}{4}$ inch.

"Signals and messages from this station were received at Poldhu by day as well as by night, but no commercial use of the station was made at that time, in consequence of the fact that although the signals came through by day as well as by night they were exceedingly weak and faint, and also because the corresponding station on the same plan had not yet been erected in Ireland.

"A further step in advance was the adoption at the transatlantic stations of the directional aerial shown in Fig. 85.*

"When this type of aerial was adopted at Glace Bay a considerable strengthening of the received signals at Poldhu was noticed. It was therefore decided to adopt the directional aerial at all long-distance stations (see p. 221).

"A further improvement introduced at Clifden and Glace Bay consisted in the adoption of air condensers, composed of insulated metallic plates suspended in air at ordinary pressure. In this manner it is possible to prevent the dissipation of energy due to losses caused by the dielectric hysteresis in the glass dielectric of the condensers previously employed; and a very appreciable economy in working, resulting from the absence of breakages of the dielectric, is effected. These air condensers, which have been in use since May of last year, have been entirely satisfactory.

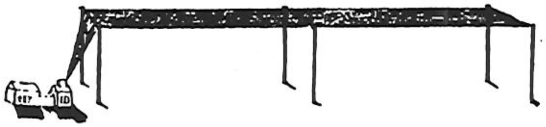


FIG. 85.—DIRECTIVE AERIAL; USED AT GLACE BAY AND CLIFDEN.

"After very considerable delay and expense, the new station at Clifden was got ready for tests by the end of May 1907, and experiments were then commenced with Glace Bay.

"The wave-length used during these tests was 12,000 feet, the capacity employed 1.6 microfarads, and the potential to which the condenser was charged 80,000 volts.

"Good signals were obtained at Cape Breton from the very commencement of the tests, but some difficulty was encountered in consequence of the effects of atmospheric electricity due to the prevalence of thunderstorms in the eastern part of Canada during the first few days of the tests.

---

* "'On Methods whereby the Radiation of Electric Waves may be Mainly Confined,' &c., *Proc. Roy. Soc.*, G. Marconi, A. lxxvii., 1906.

"Simultaneously with these tests others were carried out from Poldhu to Glace Bay with a new system of transmitting apparatus, by means of which continuous or semi-continuous oscillations could be produced.

"Proportionately to the energy employed the signals from Poldhu were so much better than those from Clifden that I decided at once to adopt this new method of transmission at Glace Bay and Clifden. The apparatus which I have been using for producing continuous or closely adjacent trains of electric oscillations is as follows:*—

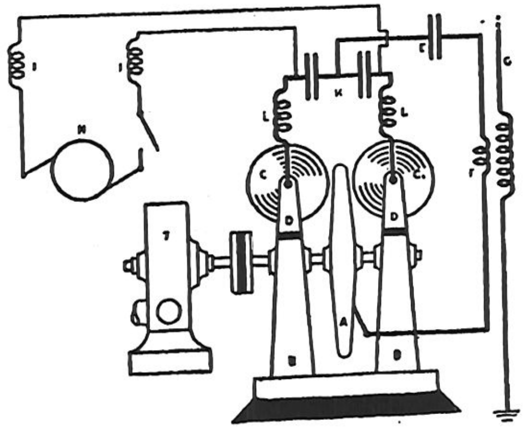


FIG. 86.—MARCONI'S UNIFORM H.F. CURRENT GENERATOR.

"A metal disc A (Fig. 86), insulated from the earth is caused to rotate at a very high speed by means of a high speed electric motor or steam turbine.

"Adjacent to this disc, which I shall call the middle disc, are placed two other discs C_1, C_2, which may be called polar discs, and which also can be rotated at a high rate of speed.

"These polar discs should have their peripheries very close to the surface or edges of the middle disc.

"If a small amount of energy is used, stationary knobs or points may be used in place of the side discs.

---

* Patent Application No. 20,119, 9th September 1907.

"The two polar discs are connected respectively through suitable brushes to the outer ends or terminals of two condensers K, joined in series, and these condensers are also connected through suitable inductive resistances to the terminals of a generator, which should be a high-tension continuous-current dynamo.

"On the high speed or middle disc a suitable brush or rubbing contact is provided, and connected between this contact and the middle point of the two condensers is inserted an oscillating circuit consisting of a condenser E in series with the inductance, which last is connected inductively or conductively to the aerial.

"If the necessary conditions are fulfilled, and a sufficient E.M.F. is employed, a discharge will pass between the outer discs and the middle disc, which discharge is neither an oscillatory spark nor an ordinary arc, and powerful oscillations will be created in the signalling condenser E and oscillatory circuit F.

"I have found that in order to obtain good effects a peripheral speed of over 100 metres per second is desirable; therefore particular precautions have to be taken in the construction of the discs. Electrical oscillations of a frequency as high as 200,000 per second can be obtained.

"The apparatus works probably in the following manner:—

"Let us imagine that the source of electricity is gradually charging the double condenser and increasing the potential at the disc, say C_1 positively and C_2 negatively; at a certain instant the potential will cause the charge to jump across one of the gaps, say between C_2 and A. This will charge the condenser E, which will then commence to oscillate, and the charge in swinging back will jump from A to C, which is charged to the opposite potential. The charge of E will again reverse, picking up energy at each reversal from the condensers K. The same process will go on indefinitely, the losses which occur in the oscillating circuit EF being made good by the energy supplied from the generator H.

"If the disc is not rotated, or rotated slowly, an ordinary arc is at once established across the small gaps, and no oscillations take place.

"The efficient cooling of the discharge by the rapidly revolving disc seems to be one of the conditions necessary for the production of the phenomena.

"By means of this apparatus, tests were carried out, but it was found, as was to be expected, that the oscillations were too continuous and of too high a frequency to affect a receiver, such as the magnetic detector, unless an interrupter was inserted in one of the circuits of the receiver. A syntonic coherer receiver would, however, work, in consequence no doubt of the considerable rise of potential which occurred at its terminals through the cumulative effect of resonance.

"The best results over long distances have, however, been obtained by a disc, in which the active surface is not smooth, but consists of a number of knobs or pegs, at the end of which the discharges take place at regular intervals. In this case, of course, the oscillations are not continuous, but consist of a regular succession of trains of undamped or slightly damped waves.

"In that manner it is possible to cause the groups of oscillations radiated to reproduce a musical note in the receiver, distinguishable in a telephone, and thereby it is easier to differentiate between the signals emanating from the transmitting station and noises caused by atmospheric electrical disturbances. By this method very efficient resonance can moreover be obtained in appropriately designed receivers."

The essential point of difference between Mr Marconi's generator and the Cram, Thomson, and Duddell circuits is this: In the latter arrangement the main oscillating circuit is in parallel with the gaseous section (the arc), while in Marconi's generator it is actually connected at one end, through condensers, to both terminals of the supply, and at the other to the middle point of the gaseous section.

Thus, if one of the gaps has no current across it, the main oscillating circuit forms a connection between the supply terminals in series with the second gap.

It has been suggested that the gaps between the electrodes form two similar arcs in series, as used by Poulsen. This cannot, however, be their function, because, if so, no oscillations whatever could be created in the main condenser circuit, since its terminals are connected to points which, under these circumstances, would be at the same potential, each point being half-way along one of the parallel branch circuits connecting the terminals of the supply.

The action must, therefore, be of a quite different character and must take place somewhat as follows: (1) The direct current from the positive terminal of the supply, which we shall suppose to be on the right hand, strikes across the gap from right to centre and rushes into the condenser of the main jig circuit. As a secondary consequence of the new distribution of charge, the negative potential on the left-hand electrode is made less, and the tendency for an arc to strike from centre to left is reduced. As the charge in the condenser increases, the current across the gap decreases, finally dying out at the moment when the charge in the condenser has reached a maximum.

The motion of the centre electrode at once restores the dielectric strength of the gap by sweeping away the ionised gas.

The centre electrode is now charged positively, the right positively and the left negatively, so the discharge next strikes across from the centre to the left. The main condenser thus discharges itself and gains a reverse charge, the centre electrode becoming negative. Hereupon the cycle recommences, its frequency being mainly dependent on the natural frequency of the main jig circuit.

The direct current component of the charge, therefore, travels by two distinct steps from the one supply terminal to the other—firstly, from the positive across the right-hand gap into the condenser, and, secondly, out of the condenser by the left-hand gap to the negative. The purely oscillating component, which will reach a steady maximum after a few cycles, travels to and from the main condenser through the circuits formed by the auxiliary condensers.

It is clear, therefore, that the gaps have never, simultaneously, arcs in series in them, under efficient working conditions. This is the more easily understood when it is remembered that the centre electrode is alternately positive and negative while the sides are fixed in sign.

I may point out that a somewhat simpler, though probably less efficient, form of this generator is possible. It would be constructed as follows: One end of a long insulated conductor, say an aerial, would be connected to the rotating centre electrode. The positive and negative terminals of the dynamo would be connected to the side electrodes. No further apparatus whatever is absolutely necessary, though it would be advantageous to connect each side electrode through a condenser to earth.

In 1910 Mr Marconi achieved a new record in long-distance transmission by receiving messages at Buenos Aires from Clifden in Ireland and Glace Bay in Nova Scotia. A large kite was used to support the aerial wire, and as, at one time, about 5,000 feet of line were out, the height of the kite must have been about 2,000 feet. The receivers used were the Marconi magnetic detector and the Fleming valve. On both good readable signals were obtained. The distance is about 6,000 miles, and is therefore the greatest over which transmission has taken place. Transmission was not attempted northwards, but, as the experiments demonstrated the possibility of practical telegraphy over the range, this was not necessary.

The interesting photograph, of which the frontispiece to this edition is a reproduction, has been given me by Mr Marconi as a sample of what is now done at his transatlantic stations. It is a portion of an actual message transmitted from Glace Bay and recorded photographically at Clifden. That an automatic record can now be made over so great a distance opens up great possibilities; such, for instance, as the employment of speeds of sending much higher than those possible when the message is read by sound, and written down by hand.

Over shorter distances Mr Poulsen has already obtained good records at fully 120 words per minute. The same will be done across the Atlantic as soon as the mechanical details of an automatic transmitter are perfected. A single wireless line of communication will then be more than equal to a modern cable.

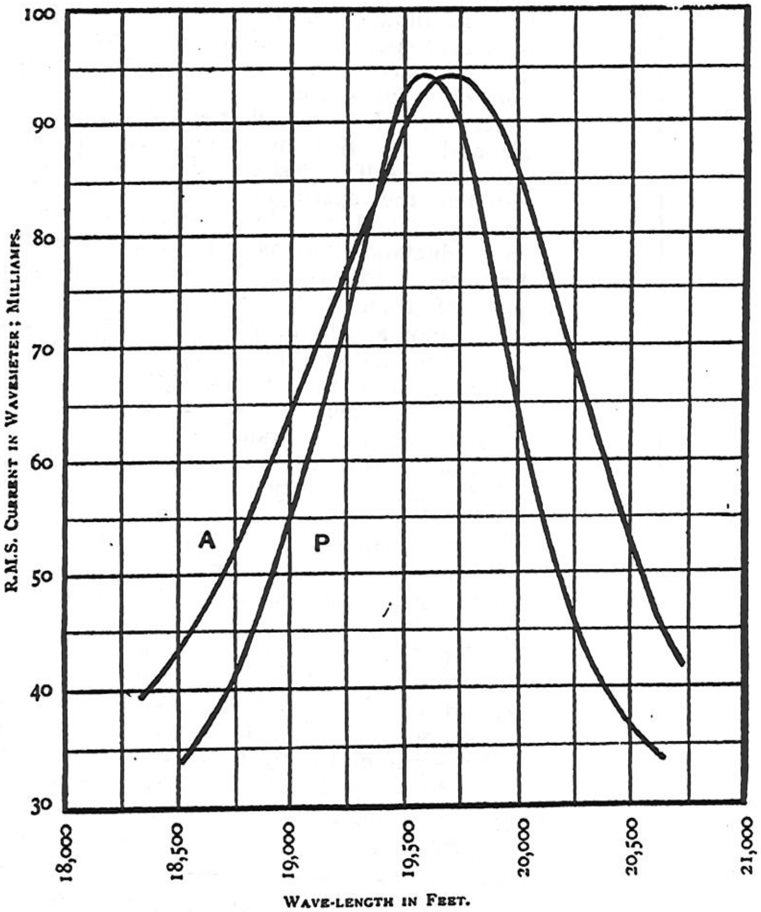


Fig. 87.—Resonance Curves of Clifden Marconi Station.

P, Primary Current, δ_1=.013; *A*, Aerial Current, δ_2=.043. (Decrement of Wavemeter=.05).

The instrument, which is actuated by the current from the detector and produces the actual record, is an Einthoven single-wire galvanometer, the movements of the spot of light recording themselves on a moving photographic film which is subsequently developed.

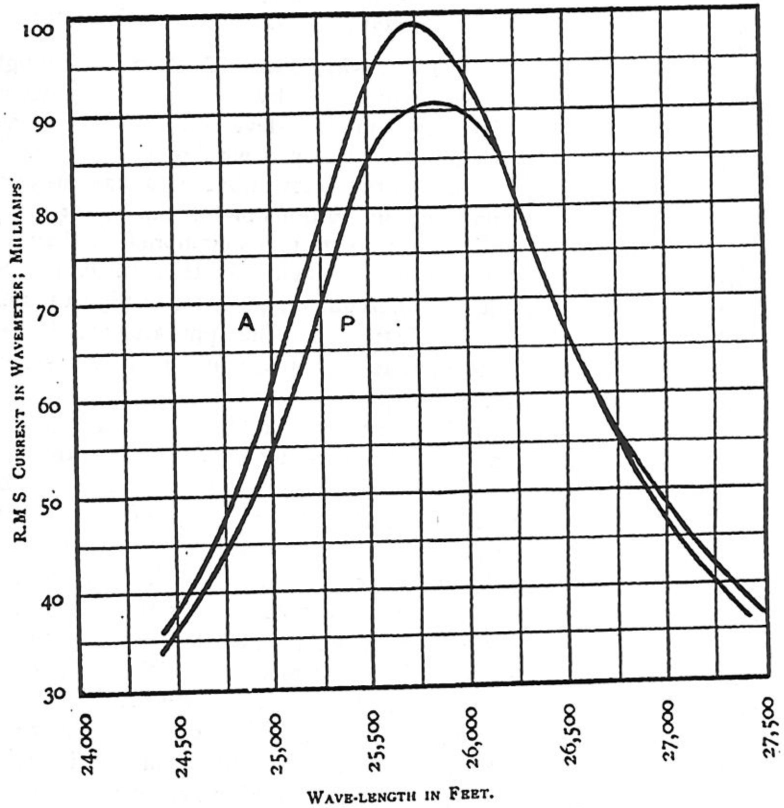


Fig. 88.—Resonance Curves of Clifden Marconi Station.

P, Primary Current, δ_1=.028; *A*, Aerial Current, δ_2=.024. (Decrement of Wavemeter=.05).

My thanks are due to Mr Marconi for allowing me to publish for the first time so interesting an evidence of the great progress now being made in wireless telegraphy, and also for the curves, Figs. 87 and 88, which show the type of current used in transmission at his transatlantic stations.

The Lodge-Muirhead System.—Although this system has been bought up by the Marconi Company the record of its inception and development remains an interesting chapter in the history of wireless telegraphy. I have therefore retained the descriptions of apparatus and working as given in earlier editions of this handbook.

Sir Oliver Lodge, realising more fully than other inventors the importance of having the transmitter and receiver of the same natural frequency, patented in 1897 a system of syntonic wireless telegraphy. The apparatus was based directly on Hertz's radiation experiments, and on his own resonating circuits and point coherer.

In Chapter II. a sketch has been given of the earlier forms. I shall now describe very fully the system now in use commercially in many parts of the world, availing myself (through the courtesy of the Lodge-Muirhead Syndicate and the proprietors of the *Electrician*) of the subjoined description by Mr H. C. Marillier, which appeared (in substance) in the *Electrician* of 27th March 1903.

Mr Marillier commences his paper with a brief reference to the preliminary tests to which the system of wireless telegraphy devised by Sir Oliver Lodge and Dr Alexander Muirhead had been subjected, with the result (he says) that the inventors now feel justified in offering it as a real advance upon any of the systems hitherto put forward, as regards clearness and accuracy of signalling.

"This claim," he goes on to say, "is well borne out by the accompanying specimen of script (Fig. 89), taken under ordinary working conditions from a siphon recorder coupled directly to a new pattern of coherer without any relay and without any tapping back apparatus, a simplification which in itself constitutes a marked and definite improvement.

"The fundamental patents on which the Lodge-Muirhead system depends were taken out for the most part in 1897, and provide for the following essentials:—

"1. The combination, in the transmitting and receiving circuits, of two capacity areas and an inductance coil, as a vital element in a syntonic system of wireless telegraphy. The capacity areas may be regarded as the two coats of a Leyden jar spread out in space, one of them being suspended in the air and the other near the earth, in fact, the earth itself if desired. Between them is situated the spark-gap, and between the spark-gap and the lower capacity area is the inductance coil as well as a condenser, both being adjustable (Fig. 90).* The purpose of these is to prolong the electrical oscillations, and by means of their adjustment to tune the radiator to any desired frequency or pitch, and thus render syntony in the receiver possible. Sir Oliver Lodge's main idea in regard to transmission has always been to obtain a succession of true waves of definite frequency, the cumulative influence of which will produce a perceptible effect on a suitably tuned receiver, no matter how feeble the waves may be, after the well-known principle of sympathetic resonance. This action is illustrated electrically in Sir Oliver Lodge's old experiment of the syntonic Leyden jars, in which the closed circuit of one jar responds to the other, so that the jar overflows or gives other signs of having become charged whenever discharge occurs in the second through its own distinct, similarly tuned circuit. The adjustability of the inductance and con-

---

* In Figs. 90, 91, and 92, 93, the top connection *a* leads to the upper, and that from *x* or x_1 to the lower insulated capacity area of the oscillator.

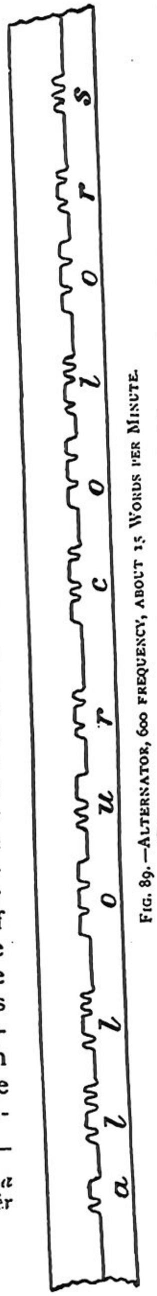


FIG. 89.—ALTERNATOR, 600 FREQUENCY, ABOUT 15 WORDS PER MINUTE.

denser render it further possible to tune the two circuits in such a way that they shall be protected against certain kinds of specified outside interference; but for very close tuning of this kind more elaborate devices are necessary, which will not be entered into in the present article.

"2. The second point claimed by the inventors is the use of a transformer, or ironless induction coil, in the receiving circuit (see tp, ts, Fig. 93). This device is probably essential in all long-distance wireless telegraphy, and should disputes arise at any future time as to the claims of individual inventors, it is a feature which might conceivably be fought over. Its purpose may be described briefly as tending to magnify the E.M.F., and putting the coherer into a second circuit, instead of in direct series with the vertical collecting wire and the lower capacity. The passage in

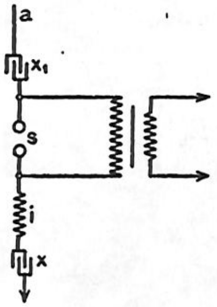


FIG. 90.—OPEN SENDING CIRCUIT.

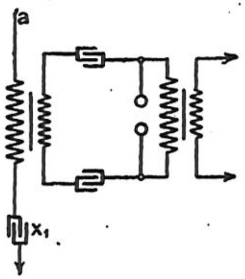


FIG. 91.—CLOSED SENDING CIRCUIT.

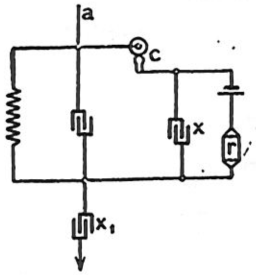


FIG. 92.—OPEN RECEIVING CIRCUIT.

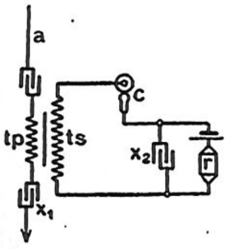


FIG. 93.—CLOSED RECEIVING CIRCUIT.

which this transformer claim occurs is as follows, and may be found in Sir Oliver Lodge's patent, No. 11,575 of 1897:—

"'In some cases I may . . . surround the syntonising coil of the resonator with another or secondary coil (constituting a sort of transformer), and make this latter coil part of the coherer circuit, so that it shall be secondarily affected by the alternating currents excited in the conductor of the resonator, and thus the coherer be stimulated by the currents in this secondary coil, rather than primarily by the currents in the syntonising coil itself; the idea being thus to leave the resonator freer to vibrate electrically without disturbance from attached wires.'

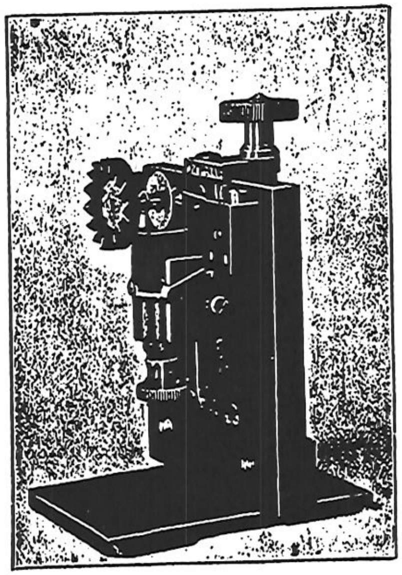
"The illustration which accompanies this description in the specification definitely indicates the transforming-up and magnification of the E.M.F.

"3. The use of a condenser shunt (x_2 in Fig. 93) in the coherer circuit, such as will enable that circuit to have a definite time period, as described in the Lodge-Muirhead patent, No. 18,644 of 1897. The addition of the condenser as a shunt eliminates the battery and receiving instrument so far as oscillations are concerned, and is regarded by the inventors as a feature of great importance. This, as well as the transformer, has been adopted in principle by other workers, and a common modification of it is to divide the secondary of the transformer in two parts and place the condenser between them. In the Lodge-Muirhead patent, No. 29,069 of 1897, the condenser is shown placed between the lower or earth capacity and the syntonising inductance coil described in 1. In practice, when a transformer is used, it has been found best to have two condensers, the one described, and another in the secondary transformer circuit (see Fig. 93).

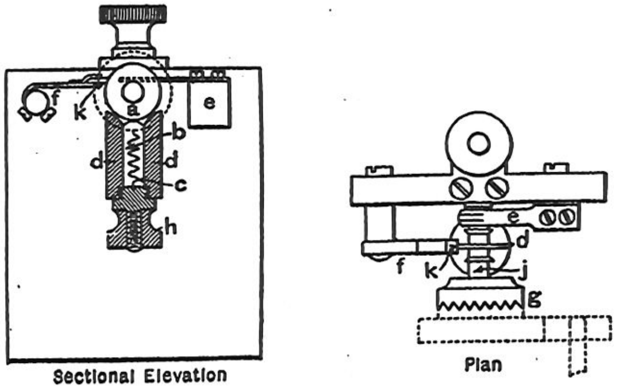
"The last-mentioned patent also provides for enclosing the coherer in a completely closed metal case, a precaution which, in the practical development of the system, is supplemented by a device which automatically short-circuits the coherer whenever the connections are switched from the receiving on to the sending apparatus.

"Besides these more or less essential features of the system, Sir Oliver Lodge and Dr Muirhead have introduced a number of detailed changes into the apparatus which tend to simplify or to improve the working. The most important of these is the new coherer. Up to a short time ago the inventors thought that they had reached the desired point of perfection in a filings-tube coherer fitted with two needle points in place of the usual plugs or knots, the tube being tapped by a constantly working clockwork tapper as shown by Sir Oliver Lodge in 1894. There are certain disadvantages, however, attendant upon all coherers in which metal filings are employed. They require a special and carefully adjusted apparatus for tapping back, and many of them are capricious in working and liable to fatigue. The new coherer introduced by Lodge and Muirhead requires no tapper, but is kept perpetually sensitive by the rotation of a small steel disc just separated from a column of mercury by a film of mineral oil. The impulse of electric oscillations breaks down the oil film and establishes momentary cohesion between the steel disc and the mercury. The coherer, without its metal case, is shown in Fig. 94, and its construction in Figs. 95 and 96, in which *a* is the rotating steel wheel, and *b* the mercury in its trough *d*, with an amalgamated spiral of platinum wire *c*, connecting it to the terminal or binding screw *h*. *e* is a copper brush making connection with the steel disc *a*, through its axle *j*. *f* is a spring carrying a small cushion of felt *k*, which rests lightly on the steel disc for the purpose of keeping its edge clean and free from dust before and after contact with the mercury. *g* are ebonite wheels which gear the steel disc to the clockwork movement actuating the siphon recorder, to the side of which the metal case containing the coherer is fixed.

"The coherer, as already mentioned, is placed directly in circuit with a siphon recorder, without the interposition of any relay, and is connected also with a potentiometer for the purpose of regulating the P.D. at its terminals from 0.03 to 0.5 volt, according to circumstances. The coherer is so sensitive, when the wheel is rotating with moderate speed, that the application of a whole volt is sufficient to break down the film of oil and establish coherence. Hence only a fraction of a battery must be used, with the rest of the circuit of appropriate low resistance; and it can readily be understood how the slightest electrical surging, producing any electrostatic effect whatever, is sufficient instantly



IG. 94.—Coherer



Sectional Elevation

Plan

Figs. 95, 96.—Coherer in Elevation and Plan.

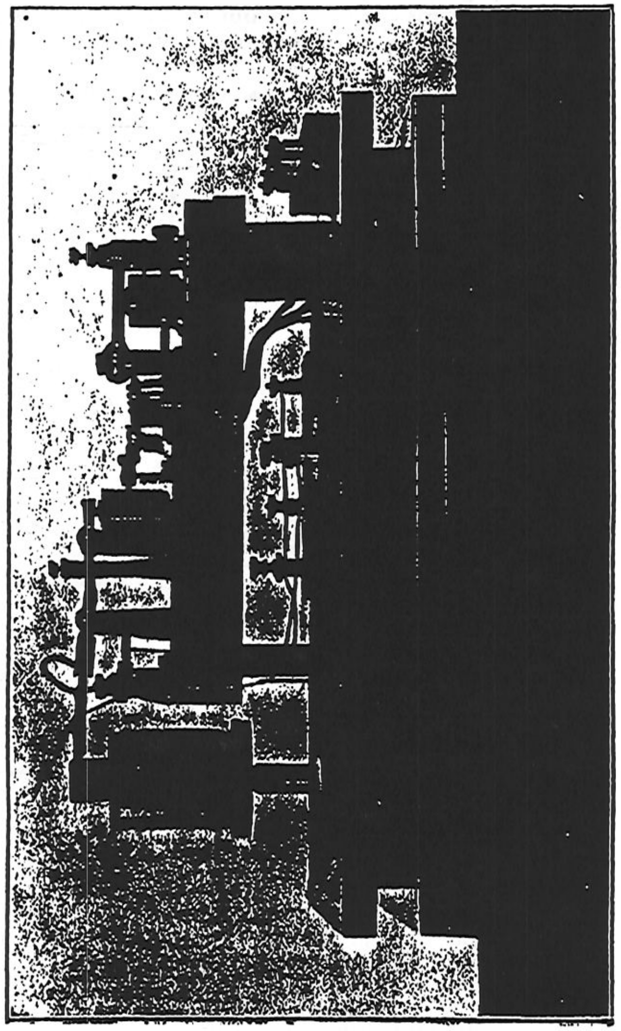


FIG. 97.—THE "BUZZER."

to break down the film, start the connection, and give the required signal. It is difficult to suppose that any recording instrument operating electrostatically can be more sensitive and more trustworthy than this simple device.

"The transmitting circuit in an ordinary open system consists essentially of an elevated capacity, preferably a large globe or a roof, although in general practice a wire cage arrangement, offering as little resistance as possible to the wind, may be used (see Figs. 102 and 104). From this capacity hangs the vertical wire, which is brought into the operating room and connected to one knob of the spark-gap. The inductance coil and condenser are connected in series with the other knob, and a lead is then taken outside again to the second capacity. The system also includes a Ruhmkorff coil for giving the sparks, and a battery of five cells, more or less, which is replaced

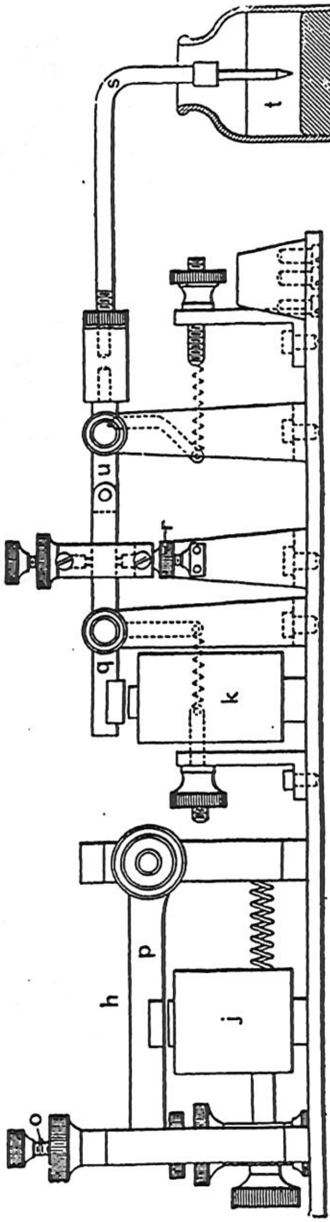


FIG. 98.—ELEVATION OF "BUZZER."

for long-distance work by an alternator. Various open and closed methods of making the connections are shown in Figs. 90 to 93, and 99 to 101.*

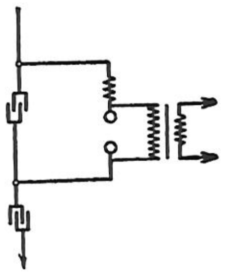


FIG. 99.—ANOTHER FORM OF CLOSED SENDING CIRCUIT.

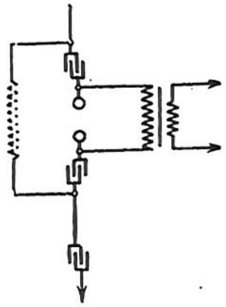


FIG. 100.—ANOTHER FORM OF CLOSED SENDING CIRCUIT.

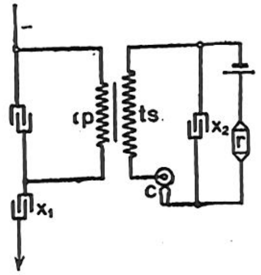


FIG. 101.—CLOSED RECEIVING CIRCUIT WITH TRANSFORMER.

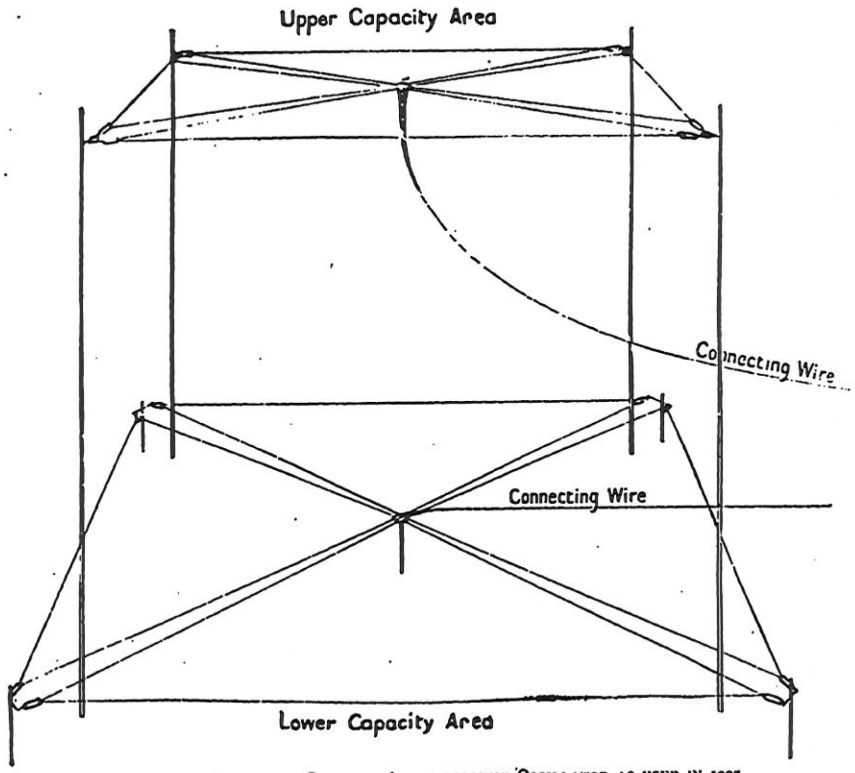


FIG. 102.—INSULATED CAPACITY AREAS FORMING OSCILLATOR AS USED IN 1907.

At the suggestion of Lieut. Carden, R.E., the aerial now consists of four independent Maltese crosses each having a leading-in wire.

"The signalling apparatus consists either of a specialised Morse key, worked by hand, or, what is a distinctive feature of Dr Muirhead's improvements, an automatic signalling machine used in conjunction with a perforator of special pattern. In either case the local signalling circuit, as arranged by Dr Muirhead, contains a transmitter designed to open and close at a definite rate the primary of the induction coil. This instrument, which is shown in Fig. 97, and more graphically in Fig. 98, is made up of two telegraphic sounders cross-connected in such a way as to act reciprocally. An aluminium arm fitted with a copper rod dipping into mercury is attached to the armature of the second sounder, and the rapid make and break between the copper rod and the mercury (about 600 times per minute) serves to fix the frequency of the sparks. The apparatus is known as a 'buzzer,' and its function is, during the holding down of the Morse key, to cut up the

---

* "See foot-note on page 154.

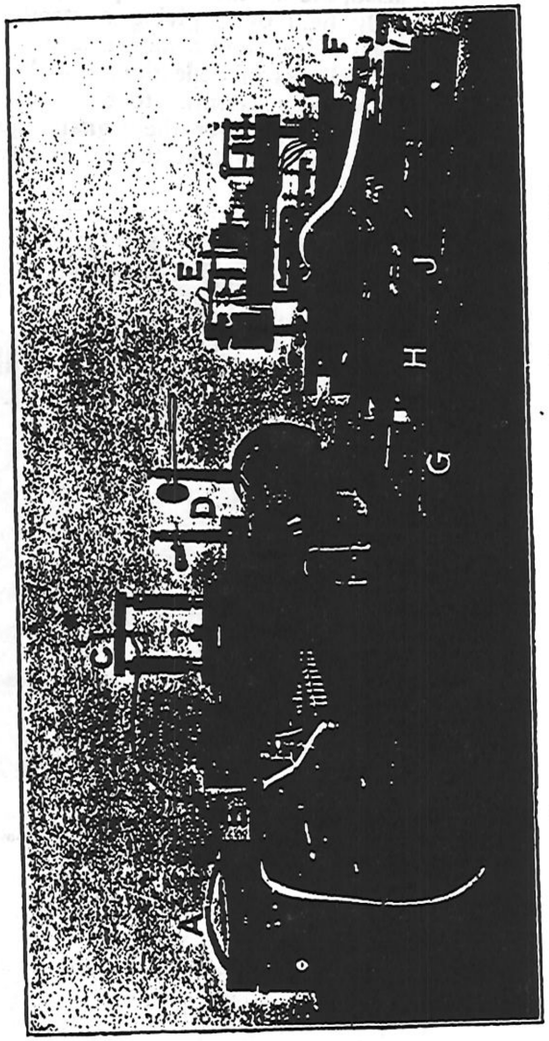
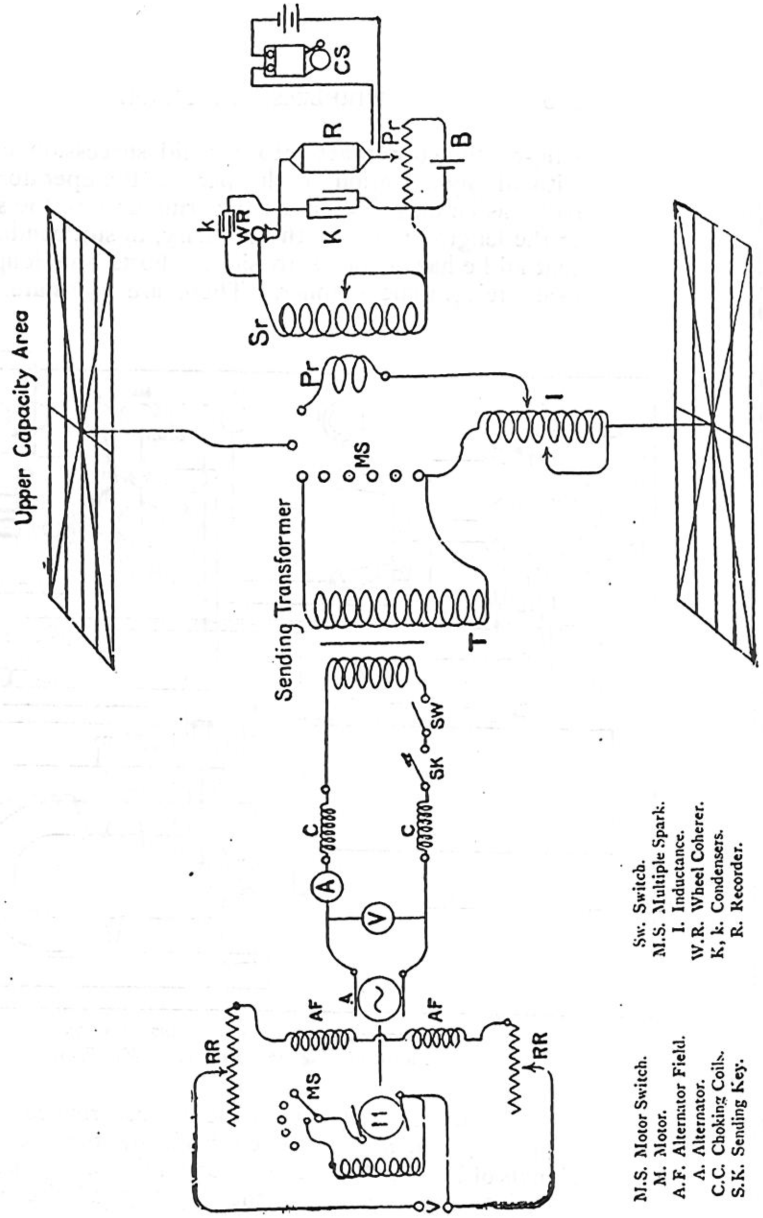


FIG. 103.—GENERAL ARRANGEMENT OF TRANSMITTING AND RECEIVING APPARATUS.
A, 12-volt Box of Secondary Cells; *B*, Complete Receiving Set; *C*, Spark Rod Frame; *D*, 10-in. Spark Coil; *E*, Buzzer; *F*, Perforator; *G*, Hand Sending Key; *H*, Primary Switch; *J*, Auto-transmitter.


Upper Capacity Area
Lower Capacity Area
Sending Transformer
T
MS
Pr
I
Sr
K
k
WR
R
CS
Pr
B
C
C
A
V
A
AF
AF
RR
RR
MS
SK
SW
V

M.S.	Motor Switch.
M.	Motor.
A.F.	Alternator Field.
A.	Alternator.
C.C.	Choking Coils.
S.K.	Sending Key.
Sw.	Switch.
M.S.	Multiple Spark.
I.	Inductance.
W.R.	Wheel Coherer.
K, k.	Condensers.
R.	Recorder.

FIG. 104.—DIAGRAM ILLUSTRATING COMPLETE TRANSMITTING AND RECEIVING STATION OF MOST RECENT TYPE.

long-continued contact into a rapid succession of sparks, without any attention on the part of the operator (save in so far as he may first adjust the armatures of the sounders, or the length of dip in the mercury, to suit conditions), so that all he has to do is to signal shorts and longs in the usual telegraphic manner. These are translated by the 'buzzer' into the requisite mode of disturbance for spark-signalling, and are translated back by the recorder into signals of long and short duration on the tape (see specimen of script illustrated). If the rapidity of the sparks is insufficiently great, the signal becomes a broken or wavy line, and not a steady deflection; but if the rapidity be increased, the waviness disappears, and the recorder needle is simply held over, giving a steady long deflection to represent a dash, and a momentary one to represent a dot. This steadiness of deflection, though pleasing to the eye, is not actually essential to the reader who, with a little practice, can decipher the signals equally well when the sparks are so slow that three separate impulses or deflections represent a dash and one a dot. It may be observed, however, that the new coherer, in combination with a recorder, follows every fluctuation and peculiarity of the received waves, and indicates any inequality and uncertainty which may occur in the sparking transmitter. This method of reception is far preferable to one which acts only through the intervention of a contact-making relay, and is

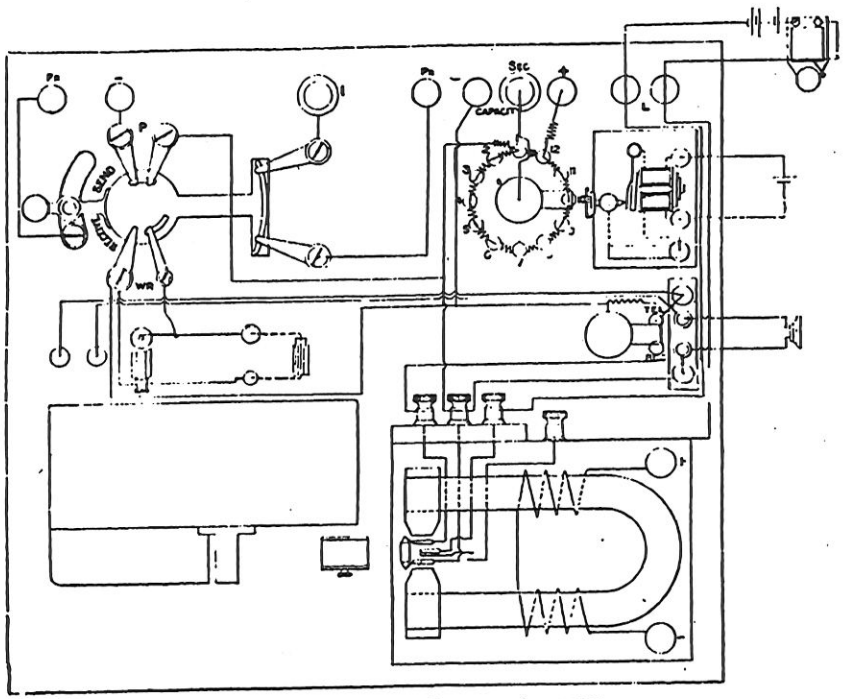


FIG. 105.—DETAILS OF RECEIVING APPARATUS.
(Compare with Fig. 106 and with right half of Fig. 104.)

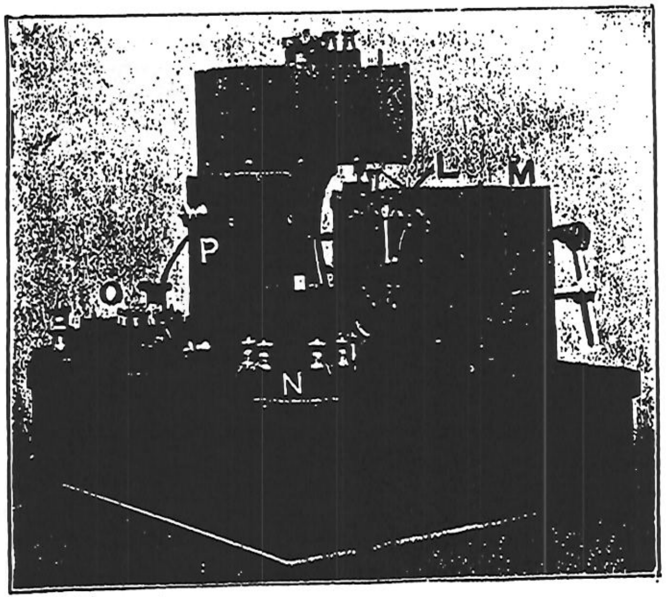


FIG. 106.—BACK VIEW OF RECEIVING APPARATUS.
K, Recorder; *L*, Coherer; *M*, Clockwork; *N*, Change-over Switch; *O*, Potentiometer; *P*, Transformer.

convenient for studying the changes which are brought about by every variation in the mode of signalling. If the signals are coming with irregular amplitudes, the legibility can be improved by limiting the excursion of the siphon recorder by the insertion of a stop, against which it shall strike, and be held over by a definite amount at each signal.

"The direct application of ordinary telegraphic signalling apparatus, both at the sending and receiving ends, is one of the most valuable features of the Lodge-Muirhead system, and is chiefly due to Dr Muirhead, who, indeed, foresaw its possibility as early as 1894, when Sir Oliver Lodge first demonstrated his early experiments before the Royal Institution."

Through the kindness of the proprietors of the *Electrician* I am enabled to make the following excerpts from the report of Mr M. G. Simpson, Electrician to the Indian Government Telegraph Department, on the establishment of wireless communication between Burma and the Andaman Islands. The report (dated 21st December 1905) forms an interesting record of a successful installation under all the adverse conditions of a tropical climate, and is a testimony to the practical value of the Lodge-Muirhead system:—

"Towards the end of August 1904 operations commenced for linking up the settlement of Port Blair in the Andaman Islands with the general telegraph system of India by establishing wireless telegraph stations at Port Blair and at Diamond Island, which is already connected by a short cable to the mainland. The distance to be spanned is 305.2 miles. Between Port Blair and Diamond Island is situated Table Island, on which is a lighthouse and close to which ships pass on the voyages Rangoon and Colombo, and Calcutta to the Straits. It was therefore decided to take the opportunity of establishing a station on Table Island, which it was hoped would prove useful to the shipping and to the Meteorological Department. This distance from Diamond Island to Table Island is 130.2 miles, and from Table Island to Port Blair

177.5 miles. A map is attached (Fig. 107) which shows the positions of the stations.

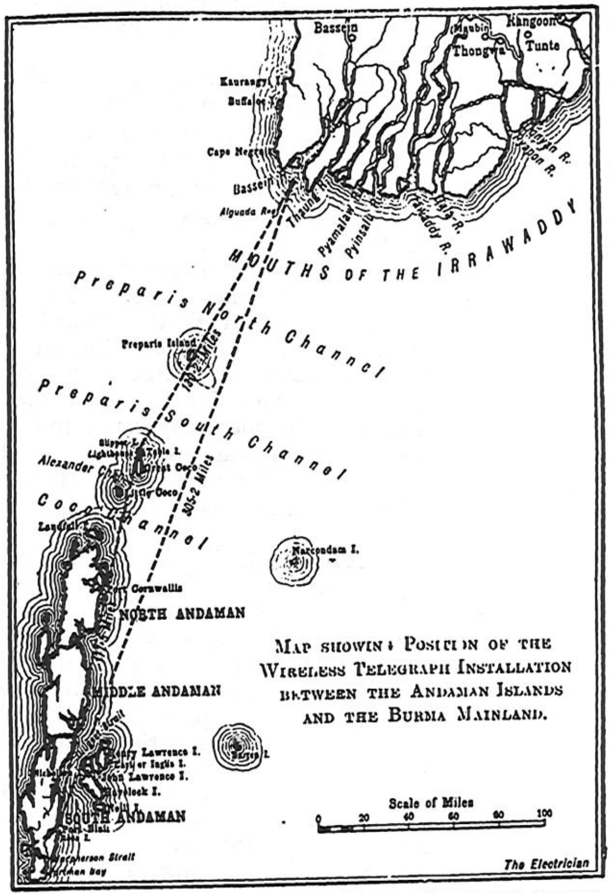

Bassein
Myaubin
Rangoon
Thongwa
Tunte
Kaurangyi I.
Buffalo I.
Cape Negrais
Bassein
Alguada Reef
Thaung R.
Pyamalaw
Pyinsalu
Irrawaddy R.
Bogale R.
Panyan R.
Rangoon R.
MOUTHS OF THE IRRAWADDY
Preparis North Channel
Preparis Island
130·2 Miles
Preparis South Channel
Slipper I.
Lighthouse
Table I.
Great Coco
Alexander Channel
Little Coco
305·2 Miles
Coco Channel
Landfall I.
Narcondam I.
Port Cornwallis
NORTH ANDAMAN
MIDDLE ANDAMAN
Henry Lawrence I.
Outram or Inglis I.
John Lawrence I.
Havelock I.
Barren I.
SOUTH ANDAMAN
Port Blair
Macpherson Strait
Rutland
Scale of Miles
0
20
40
60
80
100
Map showing Position of the Wireless Telegraph Installation between the Andaman Islands and the Burma Mainland.
The Electrician

FIG. 107.—MAP SHOWING STATIONS FOR WIRELESS TELEGRAPHY BETWEEN ANDAMAN ISLANDS AND BURMA.

"The system chosen was the Lodge-Muirhead, with which we had already experimented for three months in the early part of 1904. For this system four masts are required at each station, and as the distance to be spanned was over 300 miles, it was thought advisable to use 150 feet masts.

"I left Calcutta on 8th October 1904, with Mr J. N. Parker, assistant superintendent, one signaller, and native staff. By the same steamer went the three masts and all instruments and stores required for the station at Port Blair. The steamer arrived on 11th October, and the erection of the masts and fitting of the station was proceeded with at once.

"The Chief Commissioner placed at my disposal for the erection of the masts the services of Mr Bonig, assistant harbour master, with the requisite convict labour. The work was carried out by him with great expedition, and all four masts were erected complete by 28th October. The engine and dynamo were then fixed in position in their tent and the charging of the batteries started. The whole station was completed on 11th November and worked well with a temporary station erected on R.I.M.S. 'Minto,' which was lying up the harbour and was separated by a fair-sized hill.

"Leaving Mr Parker in charge of operations at Port Blair, I left on 7th November for Diamond Island, where I arrived on the 13th. The installation here was completed on 20th November, and attempts were made to communicate with Port Blair from the 20th to the 23rd, when a small motor broke down. As the wave measurer expected from England had not yet arrived, we were not in a position to tune the stations accurately, and could scarcely hope to attain success.

"I left Diamond Island on 25th November for Rangoon in order to take masts and stores to Table Island and to select the site for the installation. We arrived at Table Island on the morning of 30th November, and remained two days landing the stores. Having regard to the disposition of the neighbouring Cocos Island, it appeared desirable to place the wireless installation as much to the west as possible. With this object I decided to place the station, not on Table Island at all, but on Slipper Island, which is a quite small island just to the west of Table Island, and connected to it at low water by a narrow strip of land. Having selected the site for the masts, I returned to Diamond Island, arriving on 2nd December, accompanied by Mr C. Landon, assistant superintendent, who had joined me in Rangoon.

"We now continued trials between Diamond Island and Port Blair, and though we got occasional signals, we got nothing readable till the early morning of 22nd December 1904, when for ten minutes we received the first readable signals from the Andaman Islands to Burma by wireless telegraphy. Considering that the distance between these stations is 305.2 miles, and the power used was 36 volts and about 15 amperes, or only a little over ½ H.P., this result is a remarkable proof of the efficiency of the Lodge-Muirhead system.

"Experiments on the direct circuit from Diamond Island to Port Blair could not at this time be continued, as Mr Parker left Port Blair on the 22nd to come to take charge of the station at Diamond Island while I went to Table Island to complete the installation on Slipper Island. Mr Landon accompanied me, and we arrived at Table Island on 28th December.

"There is no landing place for a boat on Slipper Island. There are two landing places on Table Island, one on the south side, to be used during the north-east monsoon, and one on the north side, to be used during the south-west monsoon. The landing is very difficult in the bad weather, and often in the monsoon is impossible. Our stores were all landed on Table Island, and had to be carried across to Slipper Island when the tide permitted. The masts for this station had already been erected, and the aerial was put up and all the instruments installed by 11th January. On 12th January messages were exchanged with Diamond Island, and communication established. This circuit continued to work well till the middle of May, when an important piece of machinery broke down which could not be repaired till towards the end of June.

"I left Table Island on 17th January, leaving Mr Landon in charge of the Slipper Island installation. I arrived at Diamond Island at 7 A.M. on the morning of the 18th. The wave measurer had at last arrived, and I had just time to measure the tune of the aerial on Diamond Island before the steamer left at 10 A.M. for Port Blair, where we arrived on the 19th.

"On 30th January we were able to receive the signals both from Diamond Island, 305.2 miles, and from Slipper Island, 177.5 miles, at Port Blair, but those offices were at this time unable to receive the signals from Port Blair, though they were in communication with each other.

"It now only remained to put in at Diamond Island and Slipper Island the same tuning apparatus that we had installed at Port Blair. Mr Shields took the first available opportunity of proceeding to Diamond Island, where he arrived on 9th February, and on 10th February 1905 direct communication from Port Blair to Diamond Island was established, a number of messages being exchanged on that day. From this date on, communication had been kept up continuously, with the exception of certain interruptions to be mentioned hereafter, and the amount of traffic exchanged has been considerable, as will be seen from the statistics appended.

"At this time we were using for sending a 20-inch induction coil worked from an accumulator battery, but it was not expected this would prove powerful enough for continuous work, and 3 H.P. engines with alternators and transformers had been telegraphed for. For receiving we used telephones operated by carbon steel coherers. At first, on the circuit Slipper Island to Diamond Island, we used the Lodge-Muirhead coherer, operating a siphon recorder and giving signals on a tape, but our signallers, being always accustomed to read by sound, much preferred to read from the telephone, and the signals in a telephone operated by a carbon steel coherer were preferred by them to those in a telephone operated by the Lodge-Muirhead coherer.

"On 20th February the new 3 H.P. engines with alternators and transformers sent out by Messrs Muirhead & Co. arrived in Rangoon, and arrangements were made to get them out to the three wireless stations as soon as a steamer was available. They were landed at Diamond Island on 4th March, Slipper Island on the 5th, and Port Blair on the 6th. The engines and alternators were set up and running at Diamond Island on 6th March, and Port Blair on the 10th, and a marked improvement at once resulted in the signals, both on account of the increased loudness and improved tone.

"About this time occurred the first serious interruption. Diamond Island was unable for four days (10th March to 13th) to read the signals from Port Blair owing to atmospheric disturbances. During this time Port Blair was able to read Diamond Island signals quite well; but on a previous occasion (6th March) the reverse was the case, Diamond Island being able to read the signals from Port Blair, but Port Blair could not read the signals from Diamond Island. No serious trouble in working was experienced during the rest of March, but it was noticed that atmospheric disturbances came on nearly every afternoon, often making work difficult.

"Since April statistics were kept of the traffic exchanged; and a copy of the records for the months of April, May, and June is appended. The installation was only opened in a limited degree for State traffic, and the actual number of messages tendered and dealt with in April was only fifty-five sent from Port Blair, and thirty-nine received for Port Blair, but a great deal was sent in addition to these messages, and the traffic during the month amounted to nearly 10,000 words, and more could easily have been done had it been required. It will be noticed there were no interruptions during the month of April. During the month of May traffic exchanged amounted to nearly 14,000 words. The traffic during July, August, September, October, and November has amounted to 18,542, 21,286, 21,408, 27,398, and 26,938 words of actual messages. More could, of course, have been dealt with had it been tendered.

"It appears certain that atmospheric disturbances are more prevalent at Diamond Island than at Port Blair. The interruptions, however, to communication caused by them would have been greatly reduced, both in frequency and duration, if everything had been nice and quiet. Up to nearly the end of June the apparatus at Diamond Island was installed in a tent, and there is no doubt the signallers had to work under very great disadvantages. A perfect din was caused by the Public Works party erecting the permanent office building, which is fortunately completed now.

"Just as a land line is subject to occasional interruptions from falling trees, floods, and other physical causes, so a wireless installation of whatever system is subject to occasional interruption from electrical causes."

"The present installation we have must be regarded as being as fully reliable as an ordinary land line of about 300 miles erected through forest, and it could, I think, successfully challenge comparison with any other wireless installation of similar length in respect to regular continuous work."

Height of the Lower Capacity above the Earth.—Sir Oliver Lodge and Dr Muirhead have shown by experiment that, for a given position of the upper area, the efficiency of transmission is increased by raising the lower area to a certain height above the ground, their results being embodied in patent No. 11,271 of 1907 and a paper to the Royal Society in the end of 1908. The proper height is found to be that which gives the radiating system minimum capacity. For various conditions of the soil and subsoil it is therefore clear that this best height will be different.

A mathematical investigation which I have recently (1910) made of the conditions necessary to give maximum oscillating current in the complex circuit consisting of the upper and lower aerials and the ground below them, shows that the condition for minimum capacity is also that for equi-frequency of the parallel branches of the complex circuit and, therefore, for resonance between them. This seems to explain the phenomenon observed by Sir Oliver Lodge and Dr Muirhead.

Dr Burstyn has attacked the problem from a somewhat different point of view. Assuming, as is usually the case, that below the upper, and more or less dry, layer of earth there is a wet and much more conductive stratum, he treats the space between the lower capacity area and the ground water as a condenser in which one part of the dielectric, *i.e.*, the upper layer of soil, is partially conductive. From these premises he shows that the greater the depth of the dry upper layer the higher must the lower capacity be placed in order that the damping of the oscillations by ohmic resistance, and consequently the waste of energy, may be a minimum.

CHAPTER IX.

THE FESSENDEN SYSTEM.

PROFESSOR FESSENDEN commenced in 1897 the development of the system which has been financed by the National Electric Signalling Company. His inventions are very numerous and, in many respects, original, and his results show a precision and practicality not attained by many other experimenters in the same field.

Magnetic, thermal, and electrolytic detectors, methods of exact tuning, and even wireless telephony are covered by Mr Fessenden's patents. Among these perhaps that which has contributed most to the success of the system is the barreter. In its original form this was a thermal receiver, depending for its action on the change of resistance in a very fine platinum wire when carrying the jig current. Latterly the continuous wire has been discarded in favour of an electrolytic cell, one electrode of which is an extremely fine point. The apparatus has been described more fully in Chapter VII. An important feature of this system which greatly aids secrecy of transmission is the arrangement of the sending key which does not break the circuit, but merely alters the wave-length of the waves given out by cutting out some inductance. Thus, unless a receiving station is tuned with extreme accuracy to the transmitter, it will receive instead of signals only a long continuous dash, hence only a very sharply tuned receiver will receive a message at all. In the latest forms of apparatus the difference in frequency between the waves sent out during spaces, and those sent as signals is only

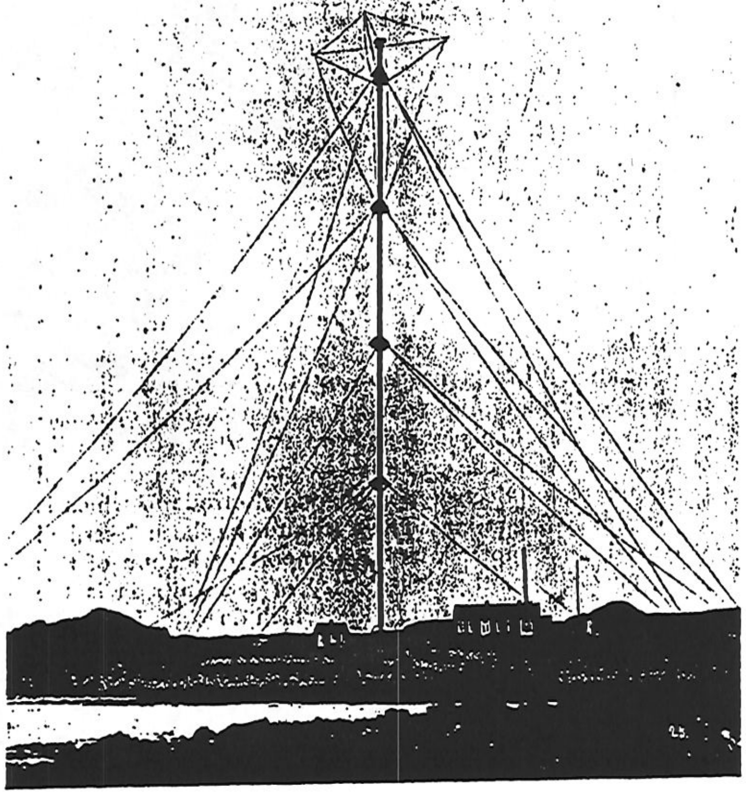


FIG. 108.—AERIAL CONDUCTOR (415 feet high), FESSENDEN SYSTEM, AT MACHRIHANISH.
A Steel Tube braced by steel wire guys divided by insulators into 50-feet sections. Capacity increased by network supported by branches near top of tube.

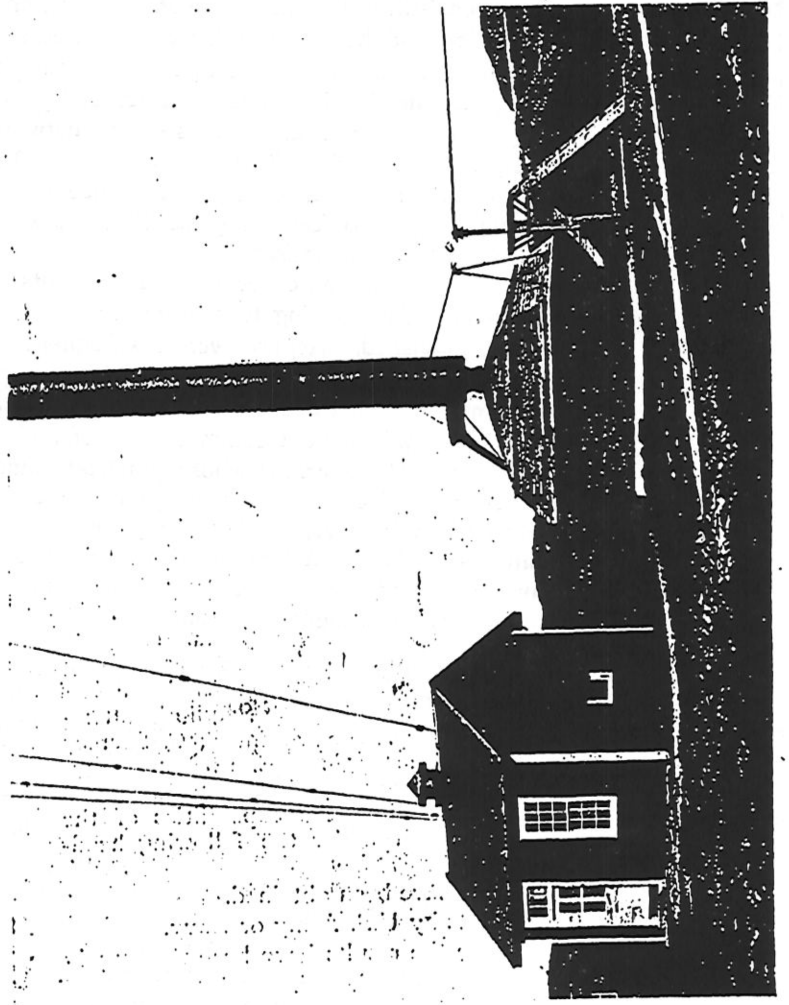


FIG. 109.—FESSENDEN'S MACHRIHANISH STATION—BASE OF AERIAL CONDUCTOR.

¼ per cent.; interception by rivals is therefore almost impossible. Mr Fessenden is apparently the first to use an aerial consisting of a steel tube standing on an insulating foundation and held in position by insulated stays. Figs. 108, 109, and 110, which have been made from photographs kindly lent me by the National Electric Signalling Company, show the aerial and details of the network of earth wires, or "wave chute," at Machrihanish. When it is mentioned that the distance between successive insulators on each stay is 50 feet, the great dimensions of the tube will be more easily realised.

Many of the more recent improvements cannot be described in detail owing to the fact that the patents are not yet published. As, however, it is frequently of greater practical utility to have well-attested facts in regard to the performance of instruments whose details are unpublished, than to follow the more common plan of giving accurate descriptions of apparatus whose practical value is still a matter of conjecture, I append some notes of results, chiefly taken from reports by experts belonging to various branches of the United States Government service, which have been kindly given me by the representative of the National Electric Signalling Company in Scotland:—

> "The National Electric Signalling Company's wireless apparatus comprises the following:—A. Sending and receiving apparatus; B. Interference preventer; C. Secrecy sender; D. Anti-atmospheric device; E. Intensity regulator; F. Wave measurer.
>
> "To avoid misunderstanding, the capabilities of the various devices are set forth under the following headings:—
>
> 1. Best results which have been obtained.
>   (*a*) In official tests by U.S. Army or Navy.
>   (*b*) In tests where the results have been thoroughly investigated and confirmed.
> 2. Results which may be expected in ordinary use.
> 3. Results guaranteed.

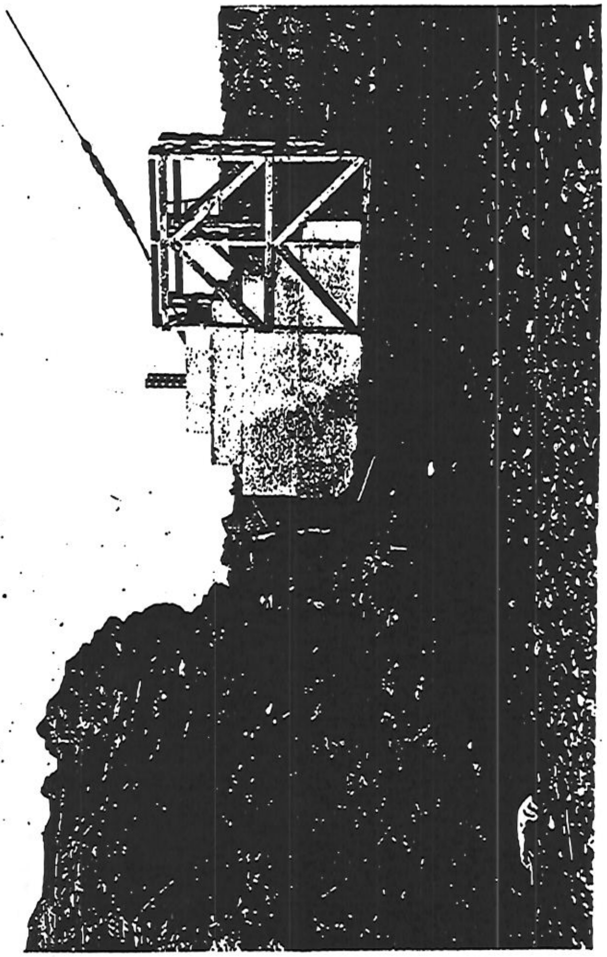


FIG. 110.—FESSENDEN'S MACHRIHANISH STATION.
Showing concrete anchor and strain insulators at end of stay, also network of earth wires (wave chute) on ground.

A. *Sending and Receiving Apparatus.*

"1. Hatteras Lightship No. 72, equipped with our apparatus, has carried on a telegraphic conversation with the U.S. Navy Station at Dry Tortugas, Fla., equipped with our liquid barreter. This distance is over 1,100 miles. Mast on lightship 75 feet high, power ½ K.W. Mast at Dry Tortugas about 180 feet high, power 3 K.W. Results obtained by Navy operators and reported officially. These results were only obtained during night time.

"U.S. vessels equipped with our apparatus lying off Norfolk communicate with more or less regularity with the stations around Boston. (Reports of Navy operators.)

"In the official tests by the U.S. Navy of the 1 K.W. sets installed on the 'Alabama' and 'Illinois,' communication was maintained over a distance of 268 nautical or 300 land miles, in daylight in the month of August, in spite of heavy atmospheric and other interference. Masts 135 feet high. Results obtained by Navy operators and embodied in official report.

"With land stations messages have been exchanged at night time between Machrihanish, Scotland, and Brant Rock, Massachusetts, a distance of 3,004 land miles.

"The results obtained with the Dry Dock 'Dewey' have been published by the Navy. The Hatteras Lightship was equipped with our apparatus complete, and the Dry Dock 'Dewey' with an infringing copy of this Company's liquid barreter and sending apparatus.

"2. With the standard 1 K.W. outfit, and masts 135 feet high, communication should be maintained under all conditions over a distance of 300 sea miles. With the 5 K.W. standard sets a distance of 500 miles should be maintained under all conditions, and with the 20 K.W. sets, suitable for installation on scouts, a distance of 800 to 1,000 miles.

"3. The distances guaranteed are as follows:—1 K.W. sets, 250 miles; 5 K.W. sets, 400 miles; 20 K.W. sets, 700 to 750 miles.

[The horse-power required therefore varies approximately as the square of the distance for distances up to 1,000 miles.—J. E.-M.]

B. *Interference Preventer.*

"1. Messages have been received with a loss of one word in twelve (easily corrected on repetition) with a 2 K.W. station operating only 226 yards away from the receiving station. (Official test.)

"Under the same conditions none of the other companies were able to receive when the interfering station was nearer than 5½ miles. (Official report.)

"When the interfering ship was so close that its signals burned out filings of the coherer used by [another] company, and the sending ship was so far away that messages could not be received on the coherer, even when the interfering ship was not interfering, the installation of the interference preventer and liquid barreter enabled messages to be received with ease while the interfering ship was trying to interfere. (Official report.)

"In this case the interfering ship was about 500 yards away from the receiving ship, and the sending ship was about 120 miles away.

"During the combined manœuvres at Fortress Monroe, the U.S. Navy vessels attempted to interfere with the stations installed by this Company for the Coast Artillery. The interfering vessels were within 2,000 yards but were absolutely unable to interfere. (Official report.)

"While messages were being received at Brant Rock from Machrihanish, a 15 K.W. station belonging to a rival company situated at Boston thirty miles away, endeavoured to interfere by sending on a tune which was not more than 3 per cent. different from the tune at which Machrihanish was sending. The interfering station was cut out and messages received from Machrihanish.

"2. With old-type interference preventer, a difference in wave-length of 3 per cent. is as a rule sufficient to cut out interference, unless the interfering station is in close proximity, in which case a 10 per cent. difference in wave-length is necessary.

"By the use of this interference preventer the signals are not weakened, but on the contrary, generally slightly increased in strength.

"With the latest improved type of interference preventer, a difference of $\frac{1}{4}$ per cent. in wave-length is sufficient for ordinary cases, and a difference of 3 per cent. where the interfering station is very close. In this case the strength of the signals is cut down to approximately $\frac{1}{2}$.

"One form of interference preventer is shown in Fig. 111. Here A is the antenna, B is a variable inductance, C and C^1 are variable capacities, D and D^1 are primaries, and E E secondaries of an Elihu Thomson or air-core transformer, F is a variable condenser, and G a liquid barreter, T a telephone, and P a potentiometer. The aerial is grounded or connected to a wave-chute at H.

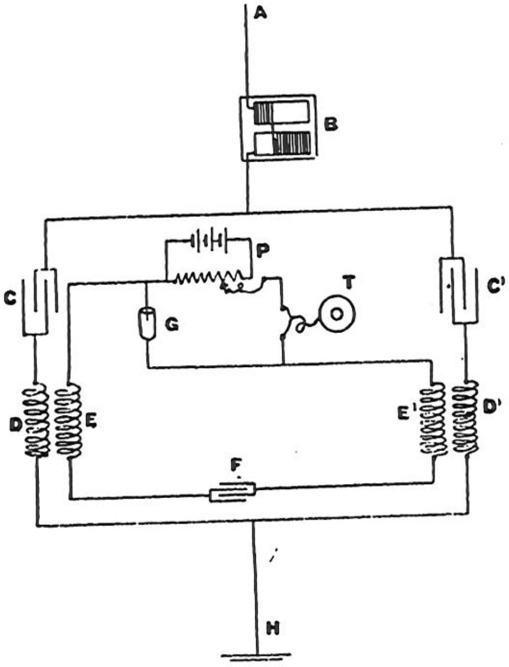


FIG. 111.—FESSENDEN'S INTERFERENCE PREVENTER.

"In this device the primaries D D^1 are similar, and so also are the secondaries E E^1. The secondaries are connected up so as to oppose each other. In practice the circuit A, B, C, D, H is tuned so as to be resonant to the frequency which it is desired to receive, the other circuit being disconnected while this is being done. The circuit A, B, C^1, D^1, H is then closed, and the variable condenser C^1 tuned until disturbing signals are cut out.

"The capacity C^1 will, as a rule, be about 5 per cent. different from the capacity C. When the difference between the wave-lengths of the sending station and interfering station is more than 3 per cent., and the stations are of equal strength and at the same distance, the signals will be strengthened by the interference preventer. When the difference in wave-length is about 1 per cent. the signals will be neither increased nor decreased. When the difference of wave-length is a quarter of 1 per cent. the signals will be weakened about one-half.

"The operation will be at once understood. When the desired frequency is received, it passes almost entirely through the side A, B, C, D, H, and affects the receiver. A frequency different from the one it is desired to receive can always be made to divide itself equally between the two branches, and, as the secondaries oppose each other, there will be no effect on the receiver.

C. *Secrecy Sender.*

"1. With the early form of secrecy sender, and a difference of wave-length of 15 per cent., on an official test five words were read by the intercepting station, distant five miles from sending station, out of 360 words.

"2. Great improvements have since been made. It is not believed that any other system can read the messages, no matter how close the intercepting station is.

D. *Anti-Atmospheric Device.*

"1. Messages have been read by the use of the interference preventer when other systems were entirely unable to read on account of atmospheric disturbances. (Official report.)

"2. It is difficult to express a guarantee in this matter, but it may be stated that in practice when the atmospheric is so strong that the noise can be heard with the telephone held six inches from the ear; when the anti-atmospheric device is connected no atmospheric can be heard at all, and the signals are not weakened at all.

"With the forms of apparatus used during the past year, atmospheric disturbances so strong that they can be heard with the telephone six feet away from the ear, are cut down by the use of the atmospheric disturbance preventer so as to be inaudible when receiving, and therefore not to interfere at all with the reception, and this without the strength of the signals being weakened.

E. *Intensity Regulator.*

"This is a device for modifying the intensity of the emitted waves without changing their wave-length, for the purpose of communicating with nearby ships.

F. *Wave Measurer.*

"1 and 2. This device is used for measuring wave-lengths, and is believed to be accurate to about ¼ of 1 per cent."

"DEPARTMENT OF THE NAVY
BUREAU OF EQUIPMENT,
WASHINGTON, 28*th November* 1904.

"TESTS OF THE FESSENDEN SYSTEM.

"91. On 15th August the representatives of the National Electric Signalling Company began to install the Fessenden instruments at the Navy Yard station, and on the 19th at the Highlands.

"(92-99. Description of rules governing the test, one rule being as follows:—'Absolutely no messages or signals to be sent by either station during the time assigned to the other station—not even an acknowledgment.')

"100. At 10 P.M. the Board adjourned until 10 A.M., 30th August, when it met to make the interference test; Captain Rodgers and Lieutenant Edgar at the Navy Yard station; Commander Peters and Commander Fiske at the Highlands station; Lieutenant-Commander Jayne on board the 'Topeka.' From 10.23 to 10.57 a press despatch of 861 words was received from the Highlands at the rate of twenty words per minute, with the loss of two words in the headline and two mistakes in the text. During this time, until 10.45, with the exception of intervals of a few minutes, the 'Topeka' was interfering continuously. The 'Topeka' was anchored off Tompkinsville, five and a half miles distant from the Navy Yard station.

"101. From 11.27 till noon the receiving ship 'Hancock' at the Navy Yard, 630 yards' distance from the Navy Yard station, and the experimental station in building §75 at the Navy Yard, 226 yards from the Navy Yard station, interfered continually. During this period the reception from the Highlands was not good, one message being received with the loss of one word in three.

"(*Note.*—The operators were not notified that this test would be made, and were not prepared with apparatus to cut out nearby interference, hence the loss of one word in three. During the dinner hour an improvised arrangement was fixed up, the results with which are given in paragraph 102. It is evident that the one word lost in every twelve could have been obtained by repeating the message, but no repetition was allowed.)

"102. At noon the Board took a recess until 2.15, then met and continued the test for interference. The station at building §75 interfered from 2.15 until 3 P.M. During this period the average loss was one word in twelve, in a message sent from the Highlands. From 3.15 to 3.45 the secrecy sender was tested. A message of 362 words was sent from the Navy Yard station to the Highlands by a Navy operator, at the rate of thirteen words per minute (Continental Morse); with a secrecy sender. The 'Topeka' had instructions during this period to read the message if possible.

"103. [Relates to time Board adjourned.]

"104. [Gives names of operators.]

"105. At 3.25 P.M., 29th August, Professor Fessenden sent a message to Philadelphia for his operator at that station to come to the New York Navy Yards; the message was acknowledged at once, and the operator appeared at the Navy Yard station at about 7.30 P.M. Both of these messages were read at the Highlands. He brought with him record showing that he had received, in Philadelphia, messages sent from the Navy Yard to the Highlands, one of which was a difficult code message.

"106. The Slaby-Arco apparatus was used aboard the 'Topeka.'

"107. The U.S.S. 'Hancock,' with improvised instruments, used a maximum spark of ¼ inch, 15 amperes, and 118 volts. Length of aerial, 120 feet.

"108. Building §75 used improvised instruments, spark $\frac{1}{16}$ inch. Length of aerial, 120 feet.

Address—Bureau of Equipment, Navy Department.

WASHINGTON, D.C.,
7th April 1905.

GENTLEMEN,

1. Referring to your communication of the 5th inst., requesting information as to results obtained with your apparatus by Lieutenant Hudgins, the Bureau quotes from that officer's report, as follows:—

(*a*.) "The interference preventer will practically exclude any wave varying in length by as much as 3 per cent. from the wave to which the preventer is adjusted, provided the intensity of such interfering wave is not greater than that of the wave to be received. As the interfering wave increases in relative intensity, the difference in wave-length must be increased also. Unless very accurately adjusted, the interference preventer absorbs part of the strength of the wave, and the more imperfect the adjustment the greater the absorption. The adjustment of the interference preventer is somewhat difficult, but once made it is practically constant.

(*b*.) "With this connection, it is possible to absorb or shunt to earth waves so strong that close connected they will burn out the receiver, and at the same time to build up a weak resonant wave to sufficient strength to be read. A variation of 10 per cent. in wave-length has been found sufficient to cut out waves so strong that they could not be received direct either on the electrolytic or coherer receivers, while at the same time a weak wave which the coherer would just record, was plainly received on the telephone. With waves of more nearly equal intensity, a variation of 3 per cent. in length is ample.

(*c*.) "With atmospheric or other interference the electrolytic receiver is the better. The sharp degree of tuning practicable with this receiver, permitting the tuning out of other stations unless very close to the same wave-length, or else much stronger than the wave which it is desired to receive. Atmospheric disturbances pass through the electrolytic receiver with a distinctly characteristic sound, and, unless very numerous or strong enough to burn out the fine point in this receiver, do not materially interfere with the reception of a message coming in at the same time."

—Very respectfully,

H. M. MANNING,
Chief of Bureau of Equipment.

National Electric Signalling Co.,
8th and Water Streets, Washington, D.C.

"U.S. NAVY WIRELESS TELEGRAPH STATION,
NEWPORT, RHODE ISLAND, *24th March* 1905.

"This is to certify that the interference preventer, as arranged by Mr Chas. J. Pannill of the National Electric Signalling, to my personal observation cut out the following stations absolutely:—Cape Cod, Fort Wright, New Haven; Marconi boats as well as their Siasconsett Station; Jersey City; the Fall River boats, 'Priscilla' and 'Pilgrim' (about a half hour after sailing from Newport); moderate atmospheric, also terrific atmospheric, reduced about 50 per cent., and received Nantucket Shoals Lightship, without decreasing her signals, but on the other hand increasing them as compared with receiving them on [another] company's apparatus installed at this station. All of the above stations, excepting Jersey City, which we do not get on the other apparatus, interfere with our receiving from Nantucket Shoals Lightship.

"On Saturday, 18th March, I received signals from the Fessenden Jersey City Station, which were very distinct.

"The atmospheric disturbances were so severe one night last week I was not able to receive the report of a passing steamer from the Lightship on the —— apparatus, but upon changing over to the Fessenden interference preventer, the terrific atmospheric was cut down to such an extent that I was enabled to receive the report without any trouble.

"A. Y. FORREST,
"*Electrician, 2nd Class.*"

TRANSATLANTIC EXPERIMENTS.

"Towards the end of December 1905 the National Electric Signalling Company of Washington, U.S.A., completed its two transatlantic stations, one of which is situated at Brant Rock, Massachusetts, about twenty miles south of Boston, and the other at Machrihanish, Kintyre, Scotland, the distance between the stations being a trifle over 3,000 statute miles.

"The power is developed by a boiler-engine-alternator equipment having a maximum capacity of 25 K.W. 60 cycles current. A transformer steps up the voltage to about 25,000, thus charging the condensers, which are discharged by means of a gap adjustable so as to effect the discharge at any desired point of the cycle.

"The receiver used is the liquid barreter in its latest form. The aerial is formed by a tower extending to a height of 415 feet above the ground level, and supporting a sort of umbrella formed of wires at its top. The tower is essentially a steel tube 3 feet in diameter, supported every 100 feet of its height by a set of four steel guys, there being thus sixteen guys in all. The tower is pivoted at its base on a ball and socket joint, and is insulated from the ground for a voltage of 150,000. The guys are insulated from the tower as well as from the ground, besides they are divided into 50-feet sections by means of strain insulators. One of the most serious problems to be solved was the construction of these strain insulators, which, while capable of safely transmitting the maximum stress of about 20,000 lbs., also resist an electrical tension of 15,000 volts each. The maximum deflection of the top of the tower in a 90-mile hurricane is computed to be 15½ inches. A wave chute containing over 100 miles of wire, and extending over six acres, is a very essential feature of the installation.

"On 3rd January 1906 the first signals were received from the American side, and shortly afterwards communication was established, so that messages were freely exchanged at night. The intensity of the signals received by telephone was at times so great that messages could easily be read with the diaphragm three inches from the ears of the operator. A station twenty miles distant from Brant Rock, using about

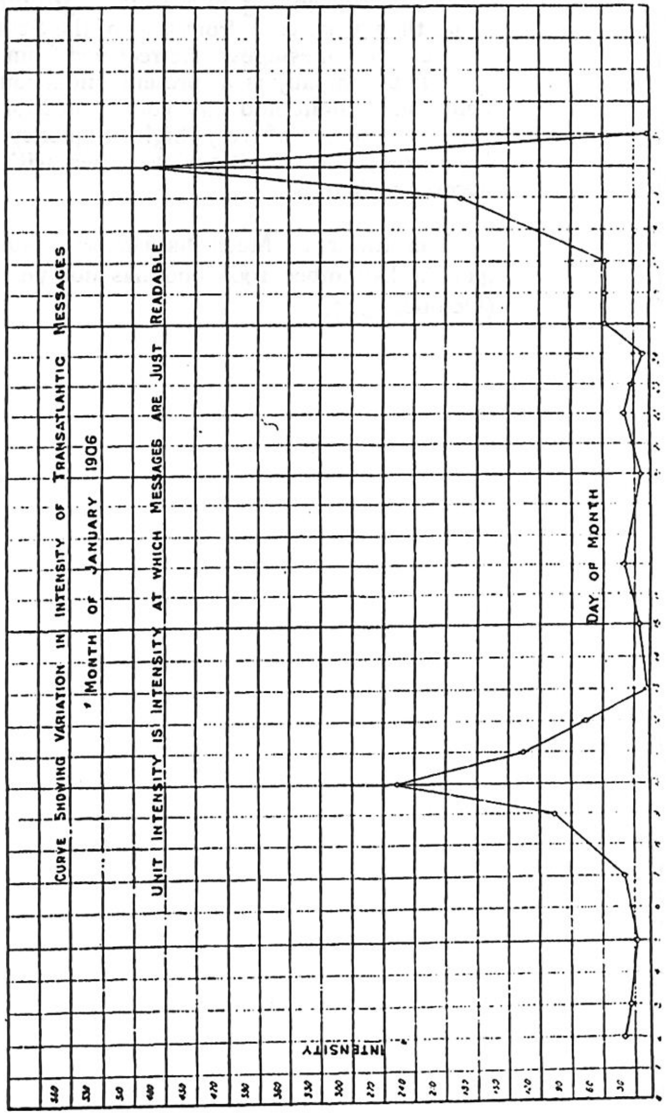


FIG. 112.

30 K.W., and sending on a wave-length differing not much more than 3 per cent. from that of the Scottish station, was cut out while messages were received from Machrihanish.

"The company is at present endeavouring to establish continuous night and day communication. With this in view alternators of very high frequency will shortly be installed at both stations, together with the apparatus accessory thereto."

The tower at Machrihanish was blown down by a gale in December 1906 and has not yet been re-erected (October 1913).

CHAPTER X.

THE HOZIER-BROWN SYSTEM.

Distinctive Features of the System.—The late Colonel Sir H. M. Hozier, and Mr S. G. Brown kindly supplied me with the following notes on their system:—

"The 'Hozier-Brown' system of wireless telegraphy does not vary from most of the other systems except in the use of a special receiver, and in the method of recording the messages received.

"The transmitter, for moderate distances up to, say, sixty miles, consists of the usual spark coil, an aerial wire of, say, 150 feet in height, and a Morse key to interrupt the current through the primary of the spark coil so as to transmit the message according to the Morse code. The receiving aerial would be of the same height, viz., 150 feet.

"The receiver, or detector, an invention of Mr S. G. Brown, consists of a pressed pellet of peroxide of lead placed between a platinum plate and a blunt lead point; the blunt lead point is carried on the end of a steel spring, and is capable of adjustment by means of a milled headed screw to press more or less lightly upon the peroxide.

"The theory of the detector is as follows:—

"The detector exerts a certain back E.M.F., which does not vary with the number of cells used in its circuit. A 2 volt accumulator in its circuit will be found to give the best results. The lead peroxide behaves as an electrolytic cell when in conjunction with its electrodes of lead and platinum. Similarly to electrolytes lead peroxide has a negative coefficient of temperature and resistance.

"The action of the normally flowing current from the storage cell is illustrated in Fig. 113. Ions of Pb (+) tend to pass upward to the lead cathode; ions of O_2 (−) downward to the platinum anode. While the detector is unaffected by Hertzian waves, however, this tendency is neutralised by the opposing tendency of the Pt. PbO_2 Pb combination to act as an independent battery sending a current in a direction the reverse to that of the external current, sending ions of $\overset{-}{O_2}$ to the lead and ions of $\overset{+}{Pb}$ to the platinum electrode. Under the influence of the alternating current resulting from the Hertzian waves, this tendency of the combination to act as a battery is brought actively into operation, with the result that the effective current sent by the external cell is diminished. When the radiation intercepted ceases, the permanent current removes the films of lead (from the bottom) and of oxygen (from the top).

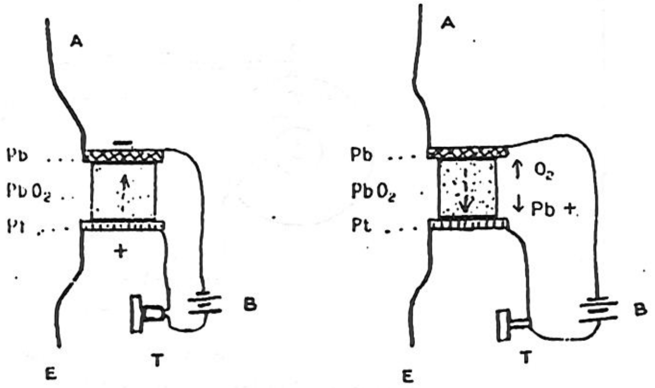


FIG. 113.—HOZIER-BROWN RECEIVER.

A, Aerial Wire; *E*, Earth; *B*, Battery of about 2 volts; *T*, Telephone Receiver. The detector consists of lead peroxide between lead and platinum plates, its voltage is normally in opposition to that of local battery, and nearly balances it (see I.). The received jigs cause action shown in II., which destroys balance of opposing E.M.F.s and causes current audible in telephone.

"That this explanation suffices, to some extent at least, is shown by the fact that if a metal (such as iron) more electro-positive relatively to platinum than lead, be used for the upper electrode, the deflection of the needle due to the first waves received is more considerable than in the case of lead, although the combination becomes less and

less sensitive to further radiation, while the 'after-creep' of recovery is very much slower than in the case of lead owing to the fact that electro-positiveness and ease of oxidation go together, and it is only very slowly that the permanent current can remove the film of oxide formed upon the iron electrode. The detector is extremely sensitive to Hertzian waves, and being dry has very little electrostatic capacity.

"As stated above, the platinum, peroxide, and lead point act as a battery when under the action of the Hertzian waves, and if joined in opposition to the external 2-volt battery, will cause the current flowing through it and round the circuit to drop in value. The detector does not act as a battery when the Hertzian waves cease, and the external battery is thus enabled to increase the current flow. It will thus be seen that the current diminishes in value when the Hertzian waves act on the detector; that is to say, the detector acts as an anti-coherer.

"The detector is quite automatic in its action. The current decreases in value on the receipt of the signal, and increases instantly in value when the Hertzian waves cease: the amount of current variation is more or less proportional to the strength of the Hertzian waves.

"There are three ways of showing or indicating the received signals. One is to place a sensitive voltmeter in the circuit, and it is not uncommon to see a variation of over half a volt registered for each signal received from a transmitter worked over fourteen miles away. A telephone in the circuit will indicate by the note the long and short signals of the Morse code sent from the distant station, and when the Hertzian waves are strong the noise in the telephone may become uncomfortably loud, while signals sent over 100 miles can usually be heard quite distinctly. The third method is to place a *siphon direct writer* in the circuit.

"The current from the detector flows round the suspended coil of the direct writer. The suspended coil hangs in a strong magnetic field, and carries a glass siphon tube; one end of the tube dips into the ink-well, the other end bears upon the moving strip of paper. On the arrival of the signals the suspended coil is deflected to one side either for a long or short space, to indicate the long or short signals of the Morse code; and thus the message is recorded on the strip of paper. (The suspended coil usually carries in addition a relay contact arm to bring in the current from a local battery, and ring a bell as a warning to the operator that a message is arriving.)

"It will be seen that (with the exception of the ringing of a bell) the message is written or recorded without the employment of any relay whatsoever, the amount of current delivered by the detector being ample to record large signals even with a moderately insensitive direct writer.

"The advantages of our detector are great sensitiveness together with great current changes, allowing the recorders to be operated directly without the employment of any relay. The detector is moreover extremely robust and cannot easily be damaged: the instrument is self-operating, works with extreme rapidity, will record as fast as any operator can send, and is practically everlasting, as it is very rarely that the peroxide pellet need be changed. As regards sensitiveness, on a 185 feet aerial signals have been received and recorded over 100 miles; this, it must be remembered, with the detector coupled directly to the aerial and to the earth-plate.

"No receiving transformer is used, the detector being coupled direct to the aerial, as before stated.

"The chemicals of the detector are carried in a brass case, together with a switch, so that on *sending* in the station, the chemicals can be disconnected from the outside circuit by turning the switch and completely isolated."

Production of Continuous High Frequency Currents for Use in Transmission.—Mr S. G. Brown has recently patented a method of producing jigs, of which the following is a description:*—

"The positive electrode, as will be seen from the figure, consists of a disc of metal, preferably aluminium, which is kept slowly rotating, the negative electrode consisting of a copper block resting against the edge of the disc. On the

passing of a direct current at 200 volts pressure through a resistance and a high self-induction, and through the disc to the copper block, exceedingly rapid oscillations were produced in a capacity shunting the moving contact.

"Measurements of the current flowing in this condenser showed by calculation that the oscillations were in some instances of the order of millions per second, and a small incandescent lamp consuming 1 ampere at 20 volts could be brilliantly lit up through a condenser of 0.005 or less of a microfarad, although the effective E.M.F. across the electrodes could not, from calculation, have exceeded 50 volts.

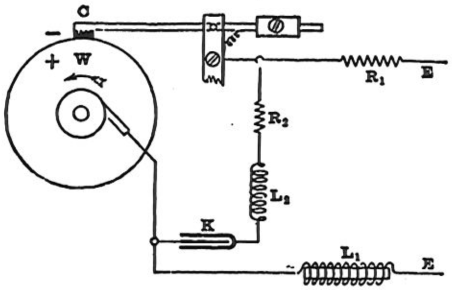


FIG. 114.—BROWN'S JIG PRODUCER.

W, rotating disc; *C*, balanced copper block; *E*, *E*, direct-current electric light leads; R_1, series regulating resistance; L_1, inductive coil of, say, 20 henries to steady current; *K*, capacity shunting contact on disc; R_2, resistance; L_2, air core inductive coil to tune circuit, although this coil is not necessary to produce oscillations through condenser.

If voltage is higher than, say, 200 volts, two or more discs and copper blocks may be employed as a multiple spark-gap.

"Many experiments with this arrangement were tried, which fully proved the existence of these high oscillations, and their continuous production; for instance, it was possible to light up an incandescent lamp through a 9-in. brick wall, employing only two loops of wire of one single turn, each enclosing an area of some 3 sq. ft., and placed on either side of the wall, the oscillations flowing in the one loop and the lamp being in the circuit of the other.

"The advantage of this moving disc was that it was self-cooling and self-regulating, this self-regulation being effected by fixing the copper block on one end of a counterbalanced arm, so that it could be adjusted to float with a definite pressure on the edge of the disc. This instrument required little or no attention, and has been worked all day without adjustment and with no appearance of change taking place."

---

* Given here by the kind permission of Mr Brown and the proprietors of the *Electrician*.

As the discharge between the copper block and aluminium disc is obviously a spark, it seems possible that this generator may be suitable for the shock-excitation method (see Chapter XIII.). There is little doubt that the discharge is due to the thin film of oxide on the disc being punctured momentarily and then rapidly healing up. As the disc moves forward fresh surfaces are continually brought under the block, so that the operation is repeated continually.

CHAPTER XI.

WIRELESS TELEGRAPHY IN ALASKA.

ONE of the first remarkable achievements in practical commercial wireless telegraphy was the installation and maintenance by the United States Army Signal Corps of wireless communication across Norton Sound, in Alaska.

Norton Sound is a great bay at the mouth of the Yukon River, 107 miles wide between the points where the wireless stations stand. One of these, St Michael, on the southern side of the bay, is the terminus of the land lines which run 1,300 miles southward to Fort Liscum, which is in communication with Seattle by a cable 1,600 miles long; the other, on the northern side, is at Safety, near Nome, the most important centre in the north-western district of Alaska. It had been found impossible to maintain a cable across the gulf on account of the ice, and the absolutely barren and snow-swept nature of the coast made an ordinary land line round it almost impossible. As Nome is the centre of a large fishing and gold-mining district it was essential to provide telegraphic communication, especially as the usual means of communication are only available during a very few months in the year.

The United States Army therefore decided, after the failure of negotiations with some commercial companies to provide a service, to establish wireless communication through the agency of the Signal Corps. Captain Leonard D. Wildman, who designed the stations, and superintended their erection and working, has most kindly favoured me with drawings and descriptions, from which the following account is taken. The detector used was the electrolytic barreter of Fessenden.

I make the following quotations from the Annual Report of the Chief Signal Officer, U.S. Army, for 1905, in order to compare the reliability of land lines and wireless telegraphy in these regions. This officer writes :—

> "The conditions considered, the continuity and reliability of the service (on the land lines) has been beyond expectation, the interruptions between Valdez and Nome the extremes of the line, being 40.7 days, or one day in nine. . . . Half of the interruptions occurred in June owing to forest fires in the upper Tanana, and unprecedented flood conditions in the lower valley. This unusually efficient service is the result of devoted field work by the Signal Corps, assisted by men of the line. . . . The interruptions during the winter were reduced to about one-half of those of previous years, due to the energy and zeal of the repair men who patrolled the line on their section."

Contrast this with the above :—

> "In August 1903 a wireless section of 107 miles across Norton Sound was established through the professional skill and exceptional ability of Captain Leonard D. Wildman, Signal Corps. This is the only long wireless telegraph system in the world, it is believed, that is regularly operated as a part of a system handling commercial business. On 6th August 1904 it completed a year of uninterrupted service over its course of 107 miles. It has handled *daily and uninterruptedly* the entire telegraphic business of Nome and the Seward Peninsula, which, together with the official business, averages several thousand words daily. More than a million words were sent during the year, many thousand being commercial code words, in which no error has ever been traced to this section. In a single hour there have been transmitted over this section 2,000 words without error or repetition. The successful installation and operation of this unique work by the officers and soldiers of the American Army afford an added illustration of their intelligence and aptitude."

It is certainly remarkable that this unique record should have been accomplished at stations, one of which was built upon a glacier, and both on a coast only accessible during about three months each year. It reflects great credit both on the designer of the stations and on those who assisted him in their working. To continue quotation :—

> "The wireless work was done by an alternate current, 500 volts, 60 cycle, 3 kilowatt generator ; a 6 horse-power gasoline, single cylinder engine, with special governor; a small grid at masthead with only two connecting wires, and large ground capacity. The dynamos, built to Wildman's plans, were provided with specially heavy insulation about the armature coils and collector rings. The switchboards were of home manufacture.
>
> "Electric storms gave little trouble, and weather or ice conditions had no material influence. The receiver was of the De Forest type (now declared to be covered by Fessenden's patents), modified by Signal Corps inventions. Captain Wildman found many opportunities for the resourceful minds of himself and his subordinates. Broken Leyden jars were successfully replaced by air condensers, the spark was muffled, currents shunted, and many other improvements applied. Captain Wildman thinks duplexing possible to a certain extent, and a call-up device probable. . . . Sergeant M'Kinney devised a key that increased the sending capacity from 15 to 30 words per minute."

The use of a practically wattless current in the primary circuit when the key is open is a feature of this system. The means for obtaining it are similar to Professor Fleming's inductive shunts on transmitting keys, but with this difference that Professor Fleming's "choking coil will stop all currents from flowing into the transformer ;"* while Captain Wildman adjusts the inductance to give a nearly wattless current in the primary. The result as proved by practical experience is a considerable reduction in the power used, and consequent saving in gasoline. This is an important economy in outlying stations.

---

* "Electric Wave Telegraphy," p. 504.

Another feature of the system is the use of two earth connections with proper inductances, one of which goes permanently through the receiver, and the other, with a small extra spark-gap in it to obviate the necessity for a switch, is used for transmitting. The arrangement was subsequently re-invented, no doubt independently, and patented by the Marconi Company.

An improvement which adds to the comfort of the operator is an arrangement whereby the main spark-gap is put outside the house. For tuning purposes there is an alternative gap inside which is not used during actual transmission.

The outside gear shows some ingenious modifications particularly useful in the stormy climate in which they were devised. The aerial, for instance, consists of two wires attached to a small grid at the top and a cross stretcher at the bottom. A rope is also fixed to the top grid, and hanging between the wires helps to bear the weight of ice which accumulates on them in winter. The lower end of the rope carries a weight which hangs clear of the ground. The whole aerial is therefore like a heavy pendulum, and is brought back to its vertical position by the weight after being deflected by a gust of wind.

We shall return to Captain Wildman's experiments on the effect of wind and moisture on transmission in a later chapter.

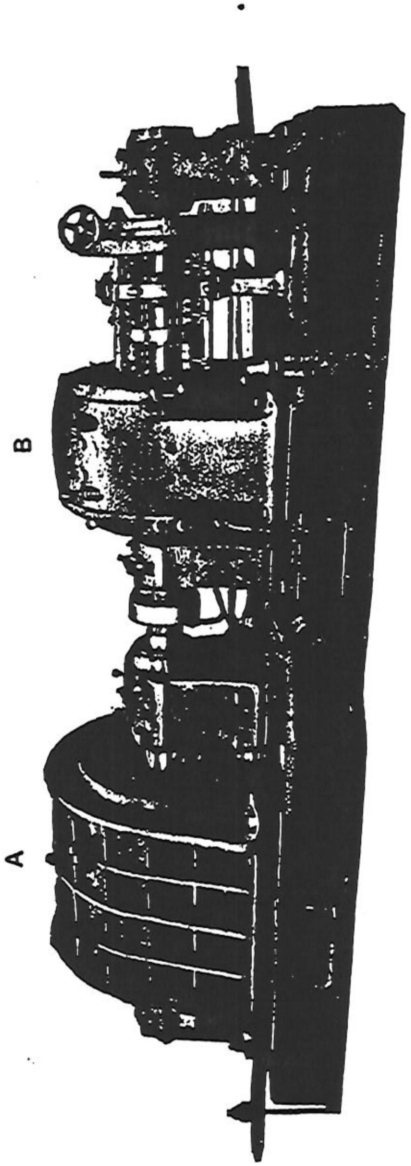


FIG. 115.—GOLDSCHMIDT HIGH-FREQUENCY ALTERNATOR OF 150 KW.
A, Alternator, 40,000~; *B*, D.C. Motor.

[*To face page 201.*

CHAPTER XII.

UNIFORM ALTERNATE CURRENT SYSTEMS.

As time goes on it becomes more and more evident that systems which transmit uniform or nearly uniform alternate current are more applicable to modern conditions than systems which transmit damped waves. This is evidenced by the increasing use of loose coupling in spark systems, by the great success of the very slightly damped shock-excitation systems, and by the development of alternating current dynamos capable of giving current at a frequency suitable for wireless transmission. A further advantage of the uniform current is, of course, its unique adaptability to wireless telephony and its convenience in high-speed telegraphic transmission. The main reason for reducing the damping lies in the necessity of avoiding interference between neighbouring stations.

The Poulsen System.—The earliest mode of producing uniform current of the necessary frequency is that of the Duddell musical arc as modified by Poulsen. In this generator an arc in hydrogen, or a hydrogen compound such as alcohol vapour, is placed in a magnetic field. In parallel with the supply leads to the arc is placed an oscillating circuit containing inductance and capacity in series. Under proper conditions a uniform high-frequency current is maintained in the oscillating circuit as long as the arc is alight. The chief conditions for the constancy of the current and frequency are fulfilled by maintaining a constant supply current and constant arc length. The

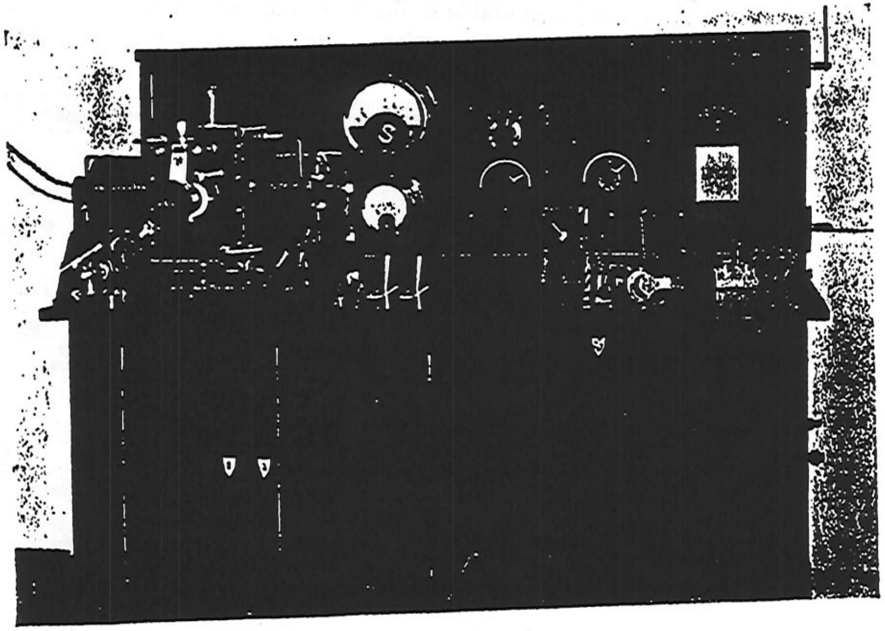


Fig. 116.—Poulsen Station.

latter condition gave some trouble at first, and its non-fulfilment in crude forms of apparatus has discouraged would-be users of the system. In modern Poulsen apparatus, however, this difficulty appears to have been satisfactorily overcome by careful construction of the generator and by causing the carbon to revolve slowly while the position of the arc is fixed so that the point on the carbon from which the arc springs is constantly shifted to a fresh part of the electrode. In Fig. 116 the small motor shown near the base of the generator accomplishes this by slowly rotating the carbon. The large electromagnet provides the magnetic field which drives the arc upwards to the point on the electrode which is highest at the moment and holds it there as the electrode turns. The effect is not only to maintain a constant arc length, but also greatly to increase the efficiency of the arc as a converter of direct to alternate current and, in addition, to increase the possible maximum voltage which can be efficiently used in the supply circuit.

It has been found possible to employ as much as 700 volts pressure in the supply to a single arc. Single generators are now working which take 35 KW. and give out about 12 KW. of high-frequency energy, and there appears to be no reason against the efficient working of considerably larger generators of the same type.

With this system wave-lengths of 1,000 m. and longer are easily obtainable; shorter waves are producible but not with so high an efficiency. The only oscillating circuit used is the antenna, the arc being placed directly in series between the earth and the antenna inductance. Since the current is uniform there is no necessity for having a separate primary circuit, and the result is a great economy and simplicity of construction due to the total absence of condensers from the transmitting circuit.

As the voltage of supply is not sufficiently high to strike across the gap between the electrodes, signalling is carried out by alteration of wave-length, the key merely cutting out 3 or 4 per cent. of the inductance by short circuiting a very few turns. The arc thus remains always alight and waves are continually radiated, but the tuning being sharp the receiver is not affected except when the transmitting key is down. A difference in wave-length of about 1 per cent. is sufficient to produce good signals in the receiver since a wave 1 per cent. too long or too short does not appreciably affect it.

Detection of Uniform Currents.—It is clear that a uniform current of high frequency cannot be heard in a telephone for two reasons, either of which is sufficient. These are (1) that frequencies above about 20,000 per second are inaudible, and (2) that the inductance of the telephone is too high to permit of the passage of a current of this or higher frequency. Other means than those in use with interrupted currents must, therefore, be employed at the receiving station, or else the transmitting current must be varied at an acoustic frequency. In the former case the most efficient detector appears to be the Pedersen "tikker," which is a vibrating interrupter, having very fine wires as contacts and connected so that it makes the circuit intermittently for short periods through the telephone. In the intervals of no connection the current in the oscillating receiving circuit has time to grow to a considerable value so that on contact being made a comparatively large charge passes from the condenser through the telephone. The instrument is, therefore, an integrator, *i.e.*, it sums up the energy of many waves before discharging through the telephone. The tikker is driven by an electric bell mechanism at such a speed as to produce a sufficiently rapid succession of contacts to give a humming sound in the telephone. The tikker ranks very high in order of sensibility among detectors. If it is desired to communicate with a station not possessing a tikker or similar arrangement, it is necessary to vary the transmitted current by an interrupter in the transmitting circuit or by using an alternate current supply to the arc. Audible signals are then produced in any ordinary type of detector circuit.

Pedersen's High-Speed Transmitter.—One of the most remarkable features of this system is the high-speed transmitter invented by Professer Pedersen, who has acted in collaboration with Dr Poulsen for a number of years. This instrument is a wonderful example of the adjustment of means to ends, and fulfils its function so well that there appears to be no reason to suppose that the very remarkable speed of 300 words per minute is by any means near its upper limit. So far the limitations have been at the receiving end, and it is probable that further improvements may even better this exceedingly useful result. High

speed of transmission is of far more importance in wireless telegraphy than in wire telegraphy, for one of the greatest causes of trouble in wireless is the occurrence of "strays" or X's, *i.e.*, of electric disturbances due to distant lightning. With ordinary manual sending, at say 20 words per minute, there will in somewhat disturbed weather be an average of perhaps one X per word, and the operator may have considerable difficulty in reading the signals correctly. If, however, transmission be at 200 words per minute, the record will show only one X per 10 words, and the legibility of signals will be proportionately greater. Of course it is impossible to use telephonic reception at such high speeds, and it is in fact necessary to obtain an automatic record of the message. This is most easily done by using a photographic recording single-wire galvanometer of the Einthoven type in connection with a rectifying detector.

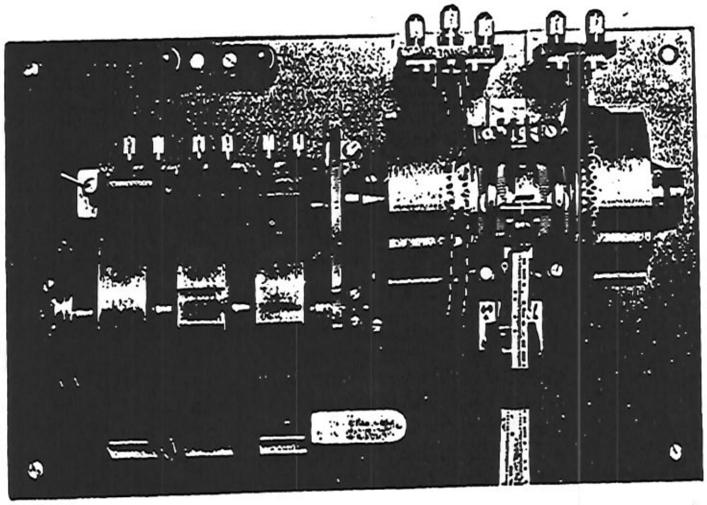


Fig. 117.—Pedersen's High-Speed Transmitter.

The Pedersen transmitter is capable of interrupting very large high-frequency currents. Its chief features are the absence of reciprocating contacts; the fact that the controlling contacts do not make and break the current, but merely connect and disconnect circuits in which no current is flowing during either operation, and that each dot or dash is produced by a single comparatively slow movement of a controlling pin.

The actual make-and-break of the current occurs on a "commutator" consisting of thick conducting bars alternated with insulating sections, against which a pair of substantial copper brushes are pressed. The current thus passes along the commutator bar from one brush to the other, and is broken by the revolution of the commutator, bringing the brushes on to an insulating section. As there is practically no limit to the size of brush or of commutator, it is clear that very large currents can be dealt with.

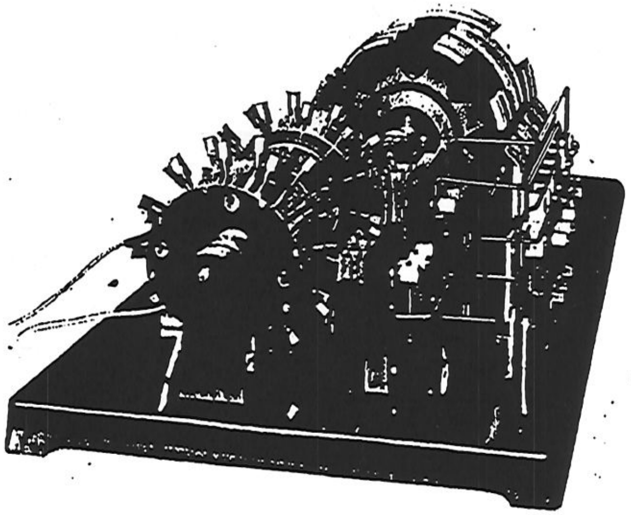


FIG. 118.—PEDERSEN'S HIGH-SPEED TRANSMITTER, LATEST PATTERN.

The sequence of operations in transmission is as follows (see Fig. 117):—The punched tape is fed into the

machine, and as a hole in it comes opposite one of the small central pins this rises and releases a controlling pin on the circumference of one of the drums. The motion of the drum brings the controlling pin between the contacts, completing the circuit to, for instance, the "dot" commutator. The brushes are still on the insulating section, but are immediately brought on to the conducting bar, and make the main circuit; they next pass off, breaking the circuit by doing so, and finally the controlling pin leaves the contacts. A dot or a dash has been sent corresponding to whether the commutator bar was a long one or a short one.

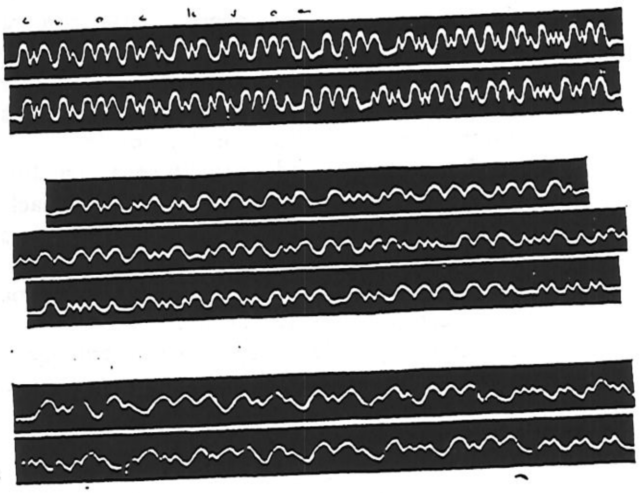


FIG. 119.—POULSEN-PEDERSEN HIGH-SPEED RECORDS.
1,400 km. 100 words per min., November 1910.

Each hole punched in the tape represents either a dot or a dash, those on the right, next the drum with a single row of pins (see Fig. 117), being dots, and those on the left side of the centre line being dashes. It will be noticed that there are two "dash" commutators and only one for dots.

This is due to the fact that while the blank intervals between the dots and dashes composing a letter of the alphabet are all of the same length, the length of a dash is equal to three dots. Thus two "dash" commutators are necessary to avoid the overlapping of dots and dashes. After the transmission of a dot the next dash pin up is one connected to the commutator on which the dash is separated by the proper interval from the dot just sent. The commutators are geared to the controlling drums so that their motions correspond. After a controlling pin has passed between the fixed contacts it is gradually drawn back towards the shaft, and before it comes round to the front of the machine is locked by the central mechanism ready to be released again if necessary by a hole in the tape. Each pin is only used once in each revolution of the drum, *e.g.*, only once in every fifty dots sent, and its cycle of motions occupies one whole period of revolution. Its motions are therefore very slow in comparison to those of a reciprocating key or relay, and the wear and tear is consequently reduced by this fact, and by the absence of mechanical shock and electrical sparking, to a negligible quantity.

In Fig. 119 some specimens of tape are shown which were received over a distance of 1,400 km., the speed being about 110 words per minute, and the supply power 17 KW. The high-speed transmitter, like the manual key, is connected as a short circuit on one or two turns of the aerial inductance.

The Poulsen system is now in commercial use in the United States, where a large amount of commercial telegraphic business is done between sixteen or seventeen stations in different parts of the continent, and between San Francisco and Honolulu. The distance between the latter stations is over 2,000 miles; it is thus the longest distance over which regular wireless telegraphy is carried on. The stations are only of 35 KW. each, which has been found sufficient for regular working. The smallness of the power

required as compared with the much greater energy used at the Marconi transatlantic stations for a somewhat smaller distance appears to be due partly to the system employed and partly to the more favourable atmospheric conditions prevalent on the Pacific.

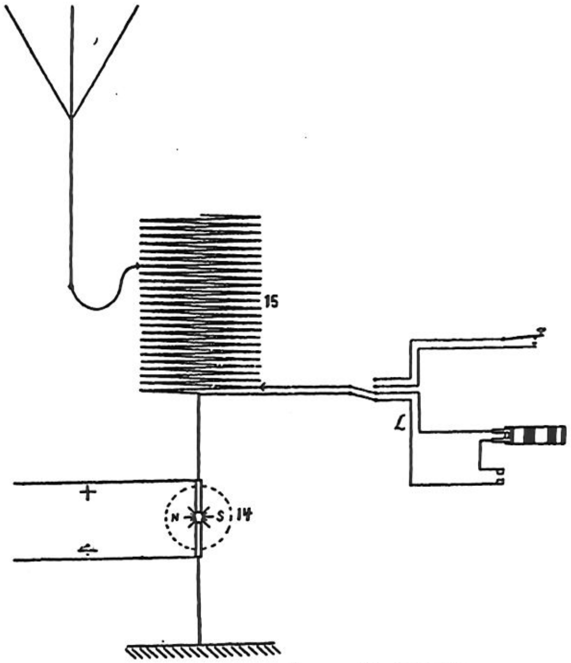


Fig. 120.—Diagram of Poulsen Transmitter.

More recently, communication in both directions has been maintained between the U.S. Navy Station at Arlington, Virginia, which was temporarily fitted with a 50 KW. Poulsen arc, and the Honolulu station. This forms the record for actual telegraphic communication in both directions, the distance being fully 5,000 miles.

Transatlantic stations are now under construction at Ballybunion, Co. Kerry, and Newcastle, New Brunswick.

The Goldschmidt System.—A description has already been given of the Goldschmidt high-frequency alternator, and it has been pointed out that it appears to be admirably suited for transmission of telegraphic and telephonic communications over long distances. Dr Goldschmidt's inventions are not limited to the transmitter alone, however. He has, for instance, invented a most ingenious receiver which should greatly simplify reception, particularly in cases where much interference by other stations or by atmospherics is to be expected.

The principle of this apparatus resembles that of the alternator; it is, in fact, a transformer of frequency. When a machine such as the Goldschmidt alternator has its stator excited by a high-frequency current, there is produced in the rotor a current whose frequency is determined by the "slip" between the rotating field of the stator and the speed of rotation of the rotor, the latter being run at a hyper-synchronous speed. If for instance, the stator be connected to a receiving aerial which is collecting current of 30,000 ~, a slip of 1.67 per cent. will cause a current to be induced in the rotor, whose frequency is 500 ~. This, of course, is perfectly audible in a telephone connected to the rotor circuit.

The peculiar advantage of this use of the induction alternator as a detector is, that the sound produced depends on the wave-length of the received current, and depends upon it in such a way that a small variation in the frequency of the incoming waves produces a large variation in the pitch of the sound. Thus in the case just given, a change of 1 per cent. in the received electrical frequency will produce a change of 60 per cent. in the acoustic frequency, *i.e.*, will give a note about a "fifth" above that of the proper signals. The possibilities which this system opens up in regard to the working of neighbouring stations without serious interference are therefore very great, and by putting the antenna slightly out of tune, atmospherics can also be differentiated. A similar result has also been

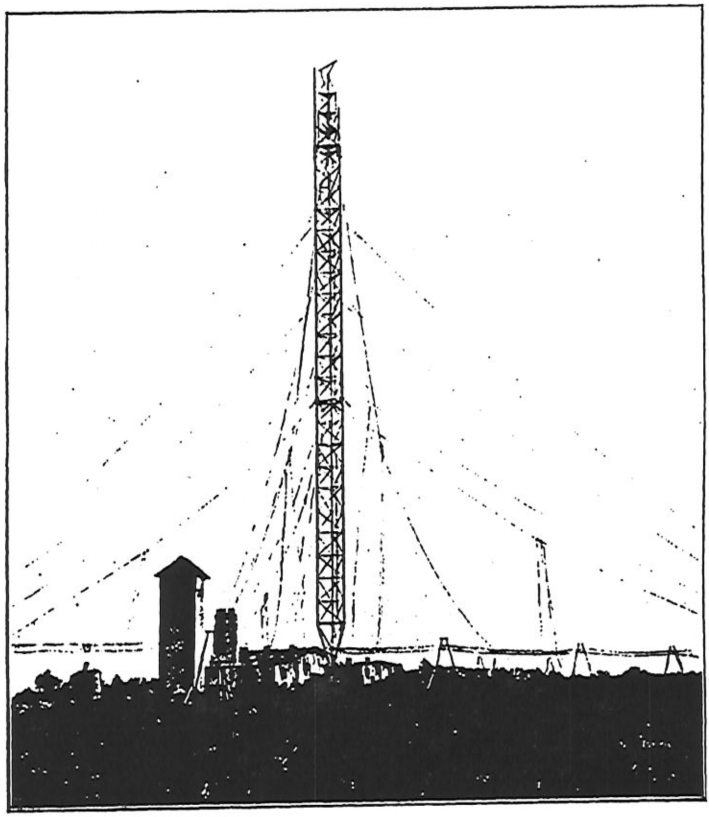


Fig. 121.—Goldschmidt High-Power Station at Eilvese, Hanover, when under Construction.

The tower (now completed) is 250 metres high. The bunch of horizontal wires carried on trestles across the view is a horizontal antenna used temporarily for experiments before completion of the tower. Communication has been established with a similar station at Tuckerton, U.S.A., 3,390 nautical miles distant.

[*To face page* 210.

attained by simpler means. A fine toothed wheel, on which a small contact brush presses, is driven at such a speed that the interruptions are very nearly synchronous with successive waves of the received current. The latter is, therefore, rectified on passing into the wheel, a note being produced in a telephone in the circuit, the pitch of which depends on the difference between the number of teeth passing per second, and the frequency of the received current. Large stations of about 150 KW. antenna energy have been erected near Hanover and on the coast of the United States near Atlantic City, which are now in permanent communication. The distance is 3,390 nautical miles, *i.e.*, nearly twice as great as that between Clifden and Glace Bay.

The source of power at the Eilvese (Hanover) Station is a Wolf semi-portable engine of 500 H.P. which drives by means of belts two D.C. dynamos each of 150 KW. From these, current is taken to supply the motor which drives the high frequency machine. The stator and rotor of the machine are wound with simple wave windings, giving 384 poles on each. At somewhat over 3,000 revolutions per minute the rotor will give current at 10,000 ~ if the stator is excited by a direct current, and higher frequencies up to 40,000 ~ are produced as is described in Chapter III.

It is notable that there is no question of the pureness of the wave produced in the antenna; it consists solely of the desired frequency, and this frequency is maintained constant by the tuned circuits, and by a very simple regulator on the motor field magnets. Telegraphic transmission is attained by the use of a modified Wheatstone Transmitter in the exciting circuit. The power in the antenna is 160 KW. at 200 amperes, and a speed of transmission of fully eighty words per minute has been obtained. The signals received at Tuckerton, U.S.A., are very strong.

CHAPTER XIII.

THE LEPEL, THE TELEFUNKEN, AND OTHER SHOCK-EXCITATION SYSTEMS.

THE method of exciting a secondary circuit by means of an extremely damped current in a primary circuit corresponds almost exactly to the sounding of a gong by striking it with a padded gong stick. The primary and the stick have so much damping that they have practically no natural period of vibration and can merely give a shock. The secondary and the gong have very definite natural frequencies and their vibrations are only slightly damped. The stick is only in contact with the gong for a very small fraction of the time that the gong vibrates, just as the primary current acts during only a small part of the time that the secondary current lasts. The gong gives its own note independent of the stick, and the secondary oscillates at its own period, whether the primary is tuned to it or not.

If the strokes follow one another rapidly the gong vibrates continuously, though the sound dies down to some extent between the strokes. If the primary discharges follow one another sufficiently rapidly the secondary current need never die out, although its strength decreases between successive impulses from the primary.

This method of producing very slightly damped current of one wave-length only, *i.e.*, without beat currents, was suggested explicitly by Wien in 1906, as the result of his observations on the currents in coupled circuits, when the

damping in the primary was made very great by reducing the spark-gap to a small fraction of a millimetre.

The characteristics of systems in which this method is used are therefore great primary damping, and the possibility of using a very close coupling without producing beat currents, also the possibility of obtaining a continuous or nearly continuous alternating current, nearly, but not quite, undamped.

There are several systems in which this method of generating high frequency current is in use. Among them those which have had the greatest commercial success are the Lepel, and its counterpart the "new" Telefunken system. There are also the Peukert and the Badische Anilin u. Soda Fabrik systems. There are no doubt older systems of generating h.f. current which may or may not act on the same principle, according as the magnitudes of the constants of their circuits were chosen ; for instance it is quite possible that Elihu Thomson's generator, described in U.S. patent No. 500,630 of 1892, may have produced its results by this method, and Professor Fessenden claims that some of his generators acted in the same way (see references, page 261). It is also possible that other experimenters may also have constructed apparatus, which behaved in the same way without recognising the essential difference between this and the ordinary spark method.

As it is certain, however, that the Lepel system acts by shock excitation, and as it has some interesting features not included in other systems, I shall describe it briefly as a type.

A complete Lepel station for a range of about 250 miles overland, with a supply of about 2½ kilowatts, is shown in Fig. 122. The transmitting apparatus, with the exception of the sending key and musical keyboard, is on the left hand and the receiver in the centre and right. Two water-cooled discharge gaps, each only a small fraction of a millimetre long between parallel metal plates, are shown at A connected in series with the condenser B and the primary inductance C. The supply leads from a direct or alternate current supply at about 1,000 volts, comes through a regulating resistance and choking coils and key D to the outer terminals of the gaps. In parallel with the primary and controlled by the keys of the musical keyboard E are a number of oscillating circuits having audible frequencies, *i.e.*, each key of the keyboard will, when depressed, cause the supply voltage to vary in time with a certain note. Hence the discharges in the generator will take place in rushes at regular intervals. The arrangement is like that of the Duddell musical arc; except that here it is not an arc but a series of sparks which is controlled by it. The sparking is very rapid, at least

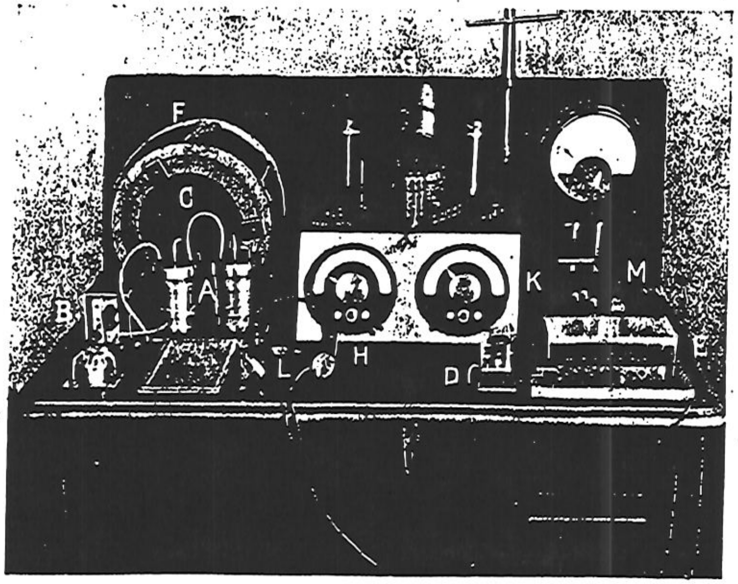


FIG. 122.—LEPEL TRANSMITTING AND RECEIVING STATION.
A, Cooled Discharge Gaps; *B*, Condenser; *C*, Primary; *D*, Key; *E*, Musical Keyboard; *F*, Secondary in Aerial; *I*, Aerial; *G*, Receiver Coupling; *H*, Variable Tuning Condensers; *K*, Detector; *L*, Telephone; *M*, Interrupter.

10,000 discharges per second, and if the musical circuits be disconnected a soft hiss or blowing noise is all that is audible.

The outer coil F is in series with the aerial and therefore forms a coupling with the primary or shock circuit. In addition to electro-magnetic coupling a direct conductive coupling is sometimes used between shock circuit and aerial.

The aerial, I, has a small vacuum tube placed near it, which by lighting up indicates when signals are being sent, as these are practically inaudible unless the musical circuit is connected.

The receiver has three circuits, one an inductance G shunted by a variable capacity H, in series with the aerial I; the second, which has a variable coupling with the first is a simple oscillator, or filter, containing only inductance, and a variable capacity; and the third, which is coupled to the second, contains detector K and telephone L with a large condenser shunting the telephone. For working without the musical note, *i.e.*, when the transmitter is only giving a soft hiss, an interrupter M and electrolytic condenser are added to the detector circuit, thus intermittently discharging the electrolytic condenser through the telephone and thus rendering the signals audible. When a musical note is used in transmission the interrupter is, of course, unnecessary.

It will be seen that this system embodies no less than three distinct preventives against interference. Firstly, the intermediate circuit acts as a filter, transmitting to the detector only currents of approximately the proper wavelength; secondly, the musical note has a very characteristic sound, and its pitch can be altered at the transmitter should it happen to be the same as that of an interfering station; and thirdly, by starting the interrupter it is possible to cut out the signals from any spark station having low-spark frequency, even if its electrical frequency be the same as that of the Lepel stations. About a hundred stations, on a modified form of this system, have been installed by the Compagnie Générale Radiotelegraphique. In these the sparks take place between a series of parallel copper rods.

The system is the invention of Baron Egbert von Lepel working in collaboration with Dr Burstyn.

The possibility of immediately changing the musical note is of assistance in the avoidance of interference, indeed musical code signals, such as bugle calls, can, as the author has pointed out, be read through almost any amount of interfering signals from other stations.

The system is now working in Jamaica and at several stations in France and Belgium. That this system of shock-excitation is electrically efficient is shown by the fact that signals from the Jamaica station, where the power supply is about 2 kilowatts, have been received in New York harbour 1,675 miles away and frequently at ranges up to 1,000 miles. The station is the property of the Direct West India Cable Company.

In the Peukert system the discharge gap consists of two parallel discs of metal almost touching one another in oil, and kept revolving in opposite directions. The discharge is thus much damped by the metal and oil, and occurs at fresh points on the surfaces each time. It is said to be very constant. Other details do not call for comment.

The New Telefunken System.—In 1908 the Telefunken Company commenced the development of a system based on Wien's suggestion, that the use of a primary circuit in which the current was much damped by a very short spark-gap, in combination with a freely oscillating aerial would form a suitable transmitter for wireless telegraphy. In theory the process is, therefore, shock-excitation, as in the case of Von Lepel's invention, but in practice the development has been on somewhat different lines. The use of alternating current has throughout been adhered to, and by employing a number of gaps in series, and a high voltage supply current, some very large power stations have been successfully constructed.

The details of the system have been very carefully worked out, including such useful adjuncts as an acoustic resonator for strengthening the telephonic signals, and many other pieces of apparatus tending to sensibility and reliability. The supply is taken from an alternator of a frequency of 500~ which has a sharply peaked current wave, and hence gives a clear note for transmission.

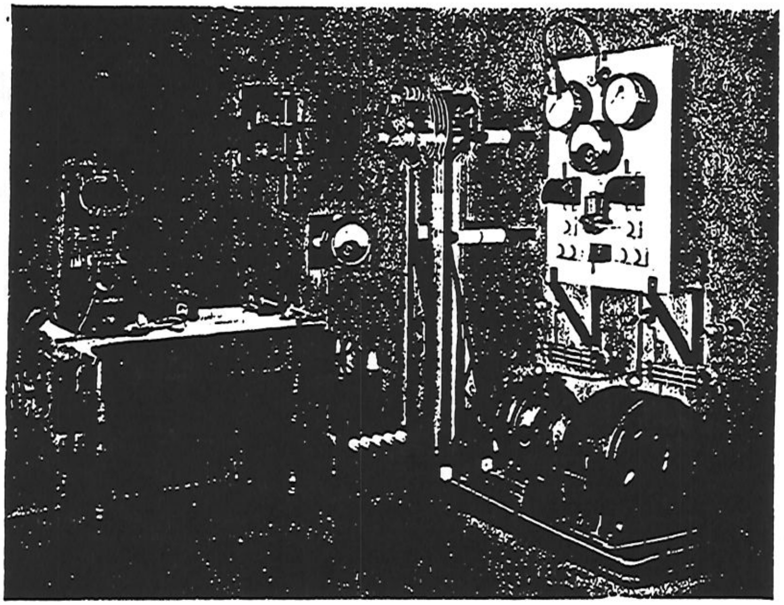


FIG. 123.—TELEFUNKEN OUTFIT FOR SHIP AND LAND STATIONS, TYPE 1.5 T.K. (OSCILLATING ENERGY, 1.5 KW.)

On the Table are the Receiver and Transmitter Key; in the corner the Primary Circuit, the Spark-Gaps being above the Leyden Jars; on the right the 500~ A.C. Dynamo and its Driving Motor.

The following paragraphs are quoted from a pamphlet issued by Messrs Siemens Bros. Ltd., who are agents in this country for the Telefunken Company.

"The new Telefunken transmitter consists of an exciting circuit which contains the quenched spark-gap. The electrically syntonised antenna system is coupled with this inductivity or conductivity. The coupling between the two systems is, on the one hand, so close that the exciting energy passes over as quickly as possible, and, on the other hand, so loose that quenching commences after the first oscillation, so that, apart from the secondary main oscillation, no further waves having an amplitude worth mentioning are perceptible."

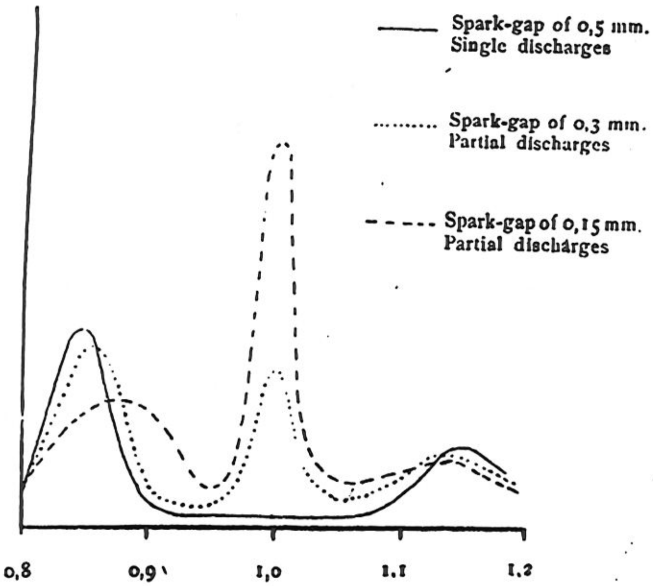


FIG. 124.—RELATIVE FREQUENCY OF OSCILLATION

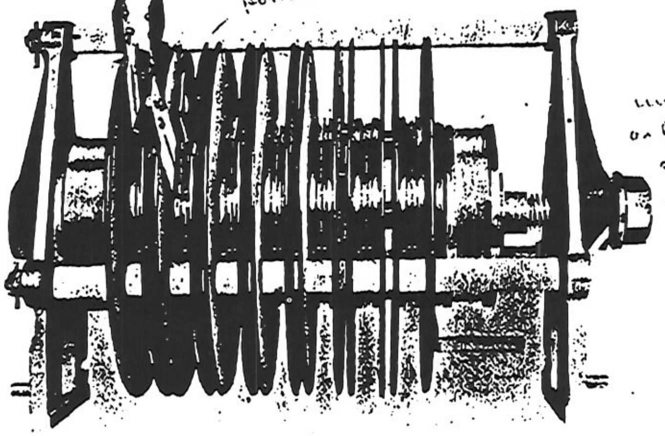
M. Wien's Resonance Curves from Secondary Circuit with different Spark Lengths in Primary, showing the transition from an ordinary coupled spark system to shock excitation of the antenna as the gap is reduced.

"The damping of the waves radiated is about 0.08-0.1 with the slowly radiating umbrella and T antenna, if the latter are working with their natural wave-length, and only 0.05-0.03 if the wave is lengthened to three or four times its natural length, since small decrements can only be attained if special measures are taken to keep all losses as low as possible."

"The new Telefunken system on the principle of tuned quenched spark-excitation has been introduced into practice since the commencement of the year 1909. In consequence of the good results immediately obtained with it everywhere, and its superiority, which was at once recognised, in the points most important to practice, such as range, working reliability, and freedom from disturbance, the demand, and, therefore, the supply of stations on the new system, has increased enormously. During the first year, only small and medium sized stations on the new system, up to 4 KW. oscillating energy, were supplied, whilst from the commencement of 1910 a series of stations up to 10 KW. oscillating energy and upwards were installed."

short circuiting plug

porcelain



[illegible]
on [illegible]
so [illegible]
[illegible]

FIG. 125.—TELEFUNKEN QUENCHED SPARK-GAP FOR 1.5 KW. OSCILLATING ENERGY.

The total number of Telefunken stations supplied on the old and new systems up to July 1910 was about 834, not including the German stations. In 1911 contracts were undertaken for 390 stations on the new system, which were to be erected in thirty different countries.

The great experimental station at Nauen, near Berlin, is being rebuilt with a tower 200 metres high supporting a very large umbrella antenna. Two machines, one of 500 ~ and the other of high frequency have been installed to supply current for this antenna. Each machine is calculated to give about 100 KW. high-frequency power. A large station has also been erected at Sayville, Long Island, U.S.A.

Owing to the higher efficiency of the shock-excitation system, the supply power required for a given distance is considerably less than that required by an ordinary spark station. Telefunken stations are now rated by the high-frequency power in the antenna and not, as is commonly done by other companies, by the supply power.

The Galletti System.—Although not yet in commercial use, the inventions and discoveries of Mr R. Galletti de Cadilhac are of great technical interest, and appear likely to take their place in practical wireless telegraphy before long. I shall, therefore, give a short account of the general principles of his apparatus.

The two chief characteristics are:—(1) The use of high voltage direct current impulses to excite the main oscillating circuit; the method is, therefore, shock-excitation of the most perfect kind; and (2) the use of a considerable number of oscillating circuits, coupled through a common condenser, which are excitated successively and automatically so as to provide a practically continuous oscillatory current of very nearly uniform amplitude in the antenna. The radiated current is thus practically uniform alternate current, and is therefore suitable for telephony as well as telegraphy.

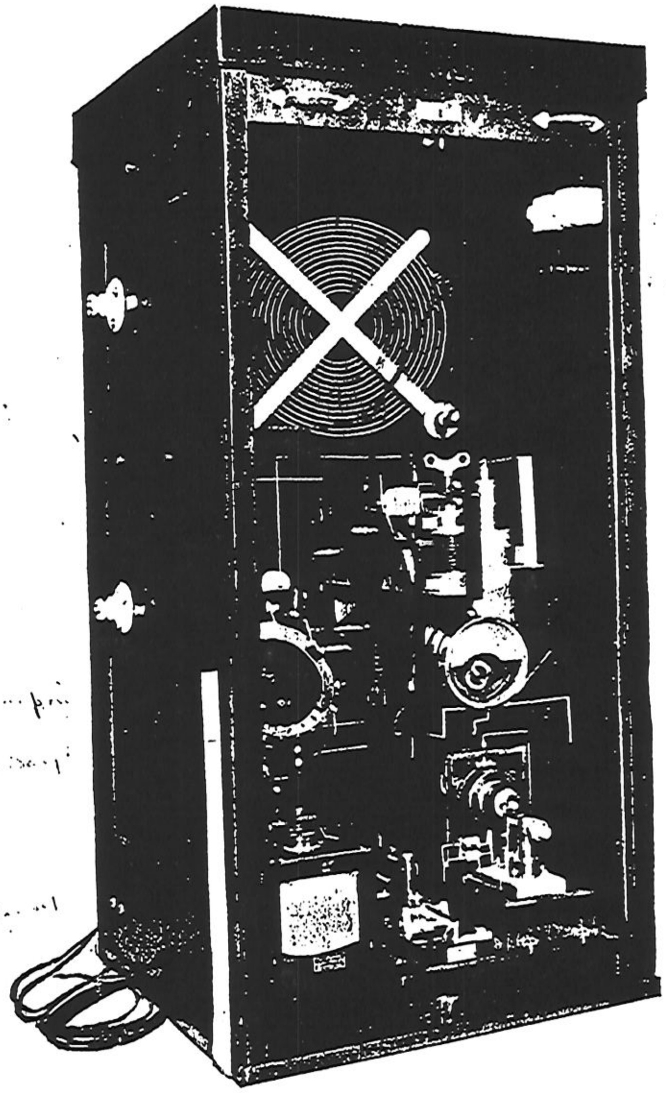


FIG. 126.—TELEFUNKEN SHIP STATION FOR RANGES UP TO 110 MILES.

[*To face page* 219.

Very high direct current voltages, ranging from 30,000 volts to over 100,000 volts have been used by Galletti in his experiments, and high energy efficiencies have been obtained. The gaseous section of the current consists of a number of gaps in series, these being closed in so as to be air-tight. The total length of the gaps is such that the spark only passes when an additional voltage is induced in them by an auxiliary apparatus.

Experimental stations have recently been erected in Switzerland, and it is understood that good results have been obtained at considerable distances.

The Lodge-Chambers System.—This is a system developed by Chambers from the section of Lodge's 1897 patent which describes a transmitter in which the aerial circuit is coupled to a primary containing capacities, inductance, and a spark-gap. The object of this arrangement as stated by Lodge was to charge the aerial by impulsive rush, and thereafter leave it "to oscillate free from any disturbance due to maintained connection with the source of electricity," and although in the light of later knowledge the word "charge" does not exactly describe the action, there is no doubt that in the apparatus as modified by Chambers, the aerial current does fulfil the desired conditions. The primary current is, of course, not a mere unidirectional charge, but it is of so short duration that it dies out entirely after a very few complete oscillations. This result is due in the earlier forms of apparatus mainly to the quenching of the primary current in the small gaps which temporarily connect the primary with the aerial. In the more recent apparatus the quenching effect is enhanced by the addition of the rotary discharger and de-tuning gap, both of which tend to shorten the duration of the primary current, so much so indeed that the other gaps may be dispensed with.

The Chambers de-tuning arrangement is an interesting device which acts by putting additional inductance into the primary circuit whenever the primary voltage becomes small, thus throwing the primary out of tune with the antenna, and preventing the return of the antenna energy to the primary. In fact, the primary is only in tune with the secondary when its voltage is sufficient to maintain sparks at both A and B (Fig. 127), for as soon as B dies out the current has to flow through the additional inductance.

On the receiving side the most interesting feature of the system is the Chambers Harmonic Selector. This instrument contains an electric circuit with variable capacity so designed that it may be tuned not to high-frequency currents, but to the spark frequency or musical-note of the received signals. Its effect in strengthening the signals to which it is tuned at the expense of interfering signals of different musical pitch is very marked, rendering discrimination between signals very much easier.

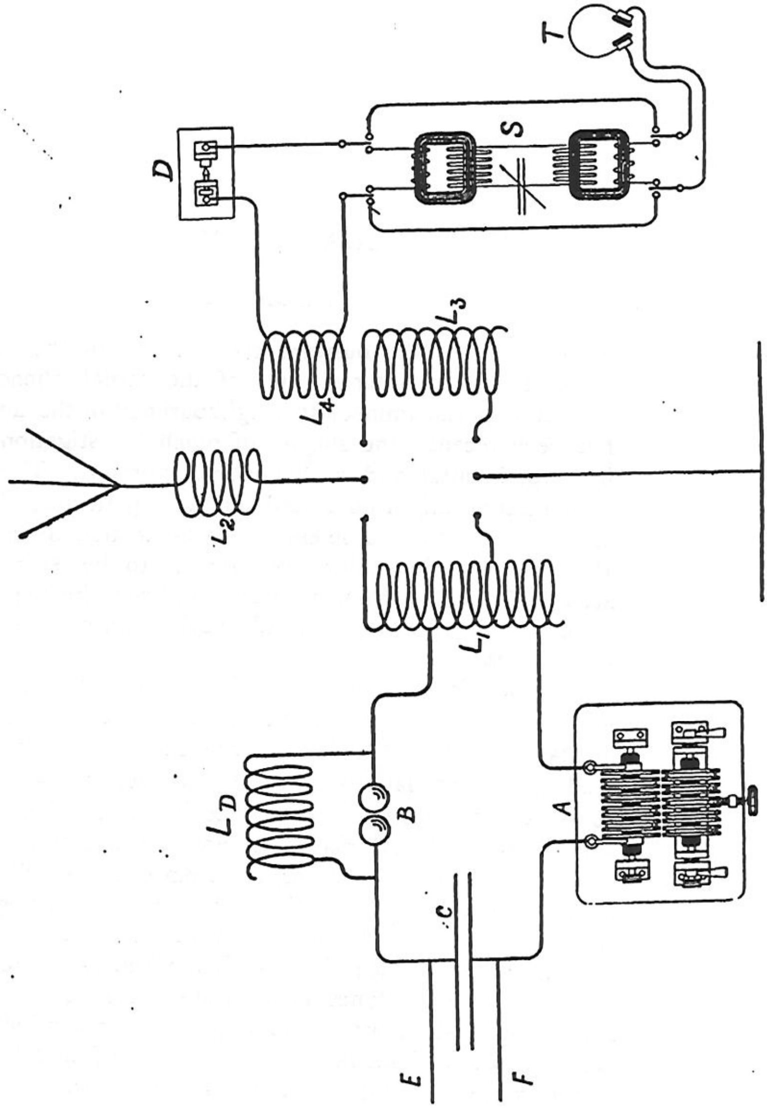


FIG. 127.—LODGE-CHAMBERS' SHOCK EXCITATION SYSTEM.

E, F, Supply Leads; *A*, Multiple Rotary Spark-Gap; *B*, Auxiliary Gap; *LD*, Chambers' De-tuning Inductance; *C*, Capacity; L_1, Primary Inductance; L_2, Aerial Tuning Inductance; L_3, L_4, Receiving Transformer; *D*, Detector; *S*, Chambers' Harmonic Selector; *T*, Telephones.

CHAPTER XIV.

ANTENNAS.

THE theory of the outward transmission of the current waves from the antenna, and of the actual phenomena occurring in the immediate neighbourhood of the antenna has been recently the subject of much investigation both by experimental and mathematical methods. The idea that the earth might be looked upon as a perfect conductor, and hence that the problem might be treated directly by Hertzian equations, has not proved to be sufficiently accurate for practical purposes, and methods which approximate more nearly to the real physical conditions are being worked out.

The fact is, as I pointed out in the first edition of this handbook, that true Hertzian telegraphy, though experimentally carried out by Mr Marconi in 1896, has not been used since that date, except, perhaps, between a pair of balloons in mid air. The difference is that, in all practical systems, transmission takes place not from one oscillator to another through an insulator, but from one part of a conductor to another part of the same, *i.e.*, transmitting and receiving stations are on the same conductor, the earth.

That the resistance of the surface of the earth must be of paramount importance in the transmission of electrical energy was first shown in the chapter on transmission in the first edition of this book, by an analysis of the measurements made by Duddell and Taylor of the currents received at Howth from a ship station at different positions in the Irish Channel.

My conclusion has been amply verified since it was published by independent workers such as Zenneck, Hack, and Sommerfeld, and by the experience of all practical wireless engineers.

Quite recently, methods for the measurement of the actual resistance in the oscillating circuit of the antenna, *i.e.*, in the circuit which includes the antenna and the earth's surface layers in its neighbourhood, have been developed, and the result of their experimental application is to show that resistance plays an important part, not only in the outward transmission of current waves over the earth's surface, but also in the limitation of the antenna current itself.

The transmitting qualities of a symmetrical antenna are determined by four numerics, viz., its Joulean resistance R, its capacity C, its inductance I, and its radiation coefficient or "radiation resistance" r. These quantities vary with the frequency of the current but are constant for any given frequency. For a non-symmetrical aerial the form must also be taken into account in practice.

To attain the best results it is clear that R must be kept as small as possible. This is not so simple as it might at first sight appear, for by far the greater part of R is due to earth resistance situated within a wave-length of the station. Austin has shown that with what might appear to be a good earth, *e.g.*, a connection to a water-pipe, R may be as high as 20 or 30 ohms in certain cases, and the author has obtained results of the same order of magnitude by another method of measurement. H. True and M. Reich have also shown experimentally that very considerable potential gradients exist in the upper layers of the ground near and under an antenna, indicating large losses of energy through Joulean dissipation.

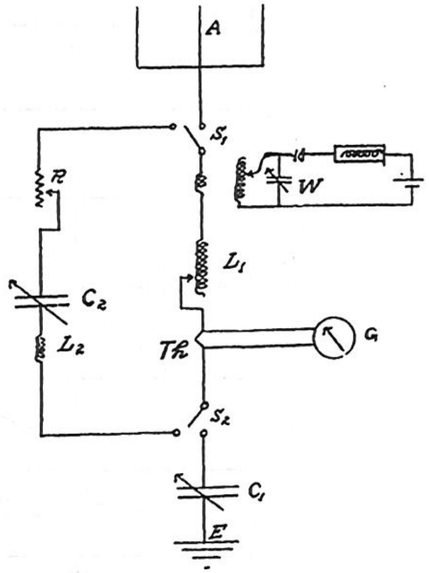
Since R represents pure loss of power it is obviously the duty of the engineer to reduce it as far as possible having regard to the cost of so doing. This may be done (1) in wet soil, by increasing the length and number of the ground wires or plates. It would appear that for the best results the ground wire net-work should extend considerably beyond the spread of the antenna; (2) on dry soil or rock, by using a large lower capacity or "counterpoise," the area of which should be greater than that of the antenna, and the best height for which is to be determined by experiment. This lower capacity has the effect of lessening the density of the lines of force when entering the ground by spreading them out; it thus reduces resistance losses.

As regards the part played by the capacity and inductance it may be noted that in general the use of a large capacity and small inductance means large currents in all the conductors, both copper and earth, while a small capacity and large inductance involves higher voltages but less current. In general, also, relatively large capacity is, in practice, accompanied by small radiation coefficient and *vice versa*.

The fourth numeric of the antenna, namely, r, the radiation coefficient or "radiation resistance," is that on which transmission actually depends. Although measurable in ohms it has a different effect on transmission from R, the Joulean resistance. The increase of r means increase of radiation of energy if uniform (or undamped) waves are being radiated; the exact opposite is true for R. The conditions are not so simple for stations in which the current is produced by the intermittent discharge of a condenser, but it is true in this case that, although in order to obtain the best results the sum $(R+r)$ may have to be limited, the greater r is in proportion to R the higher is the efficiency. From Austin's measurements it seems that this ratio is a maximum when the antenna is oscillating at its fundamental frequency, while $R+r$ is a minimum for about half the fundamental frequency.

I have not so far mentioned the actual height, h, of the antenna as one of its important numerics. The reason is that height is only valuable in so far as it increases the radiation coefficient, and there are other ways in which r may be increased, for instance by altering the form of the antenna. It appears to be true, however, that for antennas of the same type the radiation coefficient varies with the square of the height.

No direct measurements of the radiation coefficient of an antenna have hitherto been made as no experimental method was available until very recently, when I published one in the *Jahrbuch der drahtlosen Telegraphie* (see Chapter XIX.). Methods for measuring the *sum* of the Joulean and radiation resistances have been in existence for some time, the best being one which has been in use in America for the past six or seven years and is believed to have been suggested by R. A. Fessenden. This method consists in the substitution, in place of the actual aerial, of a dummy aerial consisting of the inductance of the real



A, Antenna.
E, Earth.
L_1, Tuning Inductance.
Th, Thermo-element.
G, Galvanometer.
C_2, Variable Condenser set at Antenna Capacity.
R, Resistance to bring Galvanometer Deflection to same value as Antenna Current.
W, Buzzer-driven Wave-meter.

FIG. 128.—DIAGRAM OF APPARATUS FOR MEASURING ANTENNA RESISTANCE.

aerial in series with an air condenser and non-inductive resistance. The condenser circuit is tuned to the aerial and the resistance varied until the current in it is the same as that found on switching over to the actual aerial. We may then assume that the aerial resistance $R+r$ is equal to the value of the substituted resistance, to a near approximation. The circuits may be excited by a buzzer-driven wave-meter.

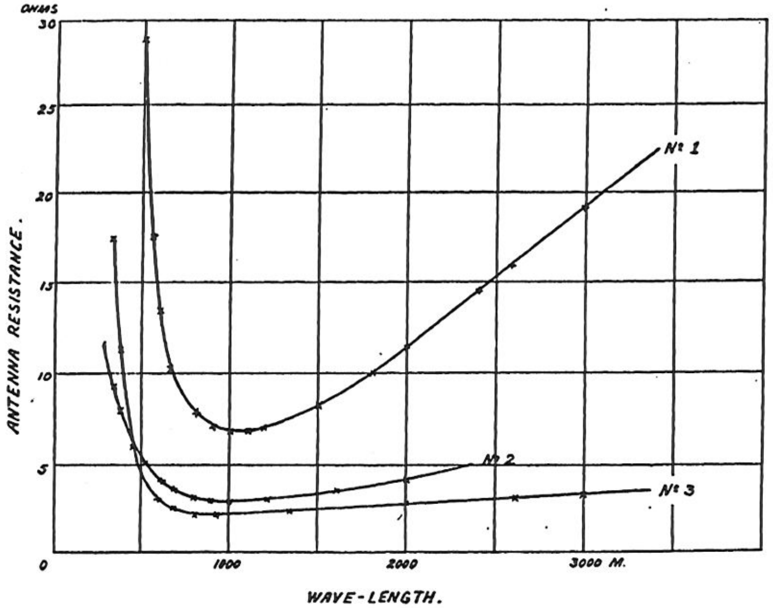


FIG. 129.—ANTENNA RESISTANCES (L. W. AUSTIN).
No. 1, Capitol Building, Washington; No. 2, U.S.S. "Massachusetts"; No. 3, U.S.S. "Maine."

The second method employed by Dr Austin in his measurement of antenna resistance was the well-known decrement method of determining resistance.* Here the antenna was excited by a wave-meter of known logarithmic decrement provided with a buzzer. The reading of the condenser of the wave-meter was noted for maximum deflection of the thermo-element in the antenna, and also when the wave-meter was thrown out of resonance by an amount sufficient to reduce the antenna thermo-element reading to one-half. The expression for the sum of the decrement is, then,

$$\delta_1+\delta_2=\pi\frac{C_m-C}{C_m},$$

where C_m denotes the condenser reading for maximum deflection and C the reading for which the deflection is reduced to one-half. As δ_1, the wave-meter decrement, is known, the equation serves to give the value of the antenna decrement δ_2. The resistance of the antenna is obtained from the decrement according to the equation

$$R=2nL\delta_2.$$

A third method is based on the Bjerknes equation of the current square in the second of two coupled circuits.

$$I^2=\frac{\text{Constant}}{\delta_1{}^2\delta_2+\delta_2{}^2\delta_1}. \tag{1}$$

Here I represents the R.M.S. current in a circuit excited inductively by another, δ_1 the decrement of the first circuit, and δ_2 that of the second. If the decrement of the first circuit is very great compared to that of the second, the second term of the denominator may be neglected, and

$$I^2=\frac{\text{Constant}}{\delta_1{}^2\delta_2},$$

that is, *doubling the resistance in the second circuit will reduce the current square to one-half.* If the antenna is excited by a highly damped circuit, the readings of a galvanometer attached to a thermo-element in the antenna will be reduced to one-half when a resistance equal to the total antenna resistance is inserted in the antenna. In practice it is impossible to obtain an exciting circuit whose decrement is great enough to allow using this method in connection with an antenna unless a correction be made for the second term of the denominator of equation (1).

---

* The description of this and of the following method are taken from Dr L. W. Austin's paper on "Antenna Resistance," *Bull. Bureau of Standards*, Vol. 9, No. 189, 1912.

TABLE I.

δ_1/δ_2	Correction per cent.	δ_1/δ_2	Correction per cent.
3	42	15	12
4	38	20	8.7
5	28	30	6.2
7	23.5	50	4.2
10	17.5		

Correction of various ratios δ_1 to δ_2 are given in Table I. These corrections are to be added to the resistance which reduces the value of I^2 to one-half to obtain the actual antenna resistance. For rough testing in the case of *quenched gap* sets, this correction may be taken as about 20 per cent. This assumes four waves in the primary train.

Of the three methods, that of the artificial antenna is undoubtedly the most accurate, while that of the half of deflection is the least so. The latter, however, is by far the simplest for ordinary station testing, as it may be applied without the use of any extra apparatus, the readings being taken with the regular hot-wire meter; sufficient suitable high frequency resistance being added to reduce the square of the antenna meter current to one-half.

For wave-lengths above 500 metres it may be assumed without great error that the high frequency resistance of

No. 20, (0.81 millimetres), Advance or manganin wire is the same as its direct-current resistance. The resistance must of course be made up non-inductively and preferably in a number of separate units. This wire will carry 7 to 8 amperes without heating.

Several types of antenna have already been described; others of importance in practice are the T antenna, in general use on merchant vessels, and the "fan." The former has a medium radiation coefficient and the latter a large one. The "roof" antenna resembles the fan in general properties, and is shaped like a high-pitched roof, as its name implies. The "umbrella" has the smallest radiation coefficient of any antenna in general use. It is, however, favoured by certain companies on account of the fact that its natural oscillation is very prolonged which tends to make sharp tuning at the receiving station possible by reducing the damping of the transmitted waves.

The author's method of measuring the radiation resistance and other constants of an antenna is given in the chapter on Efficiency (below).

Earth Connections.—A common form of earth connection is a strip of zinc plate, sunk on edge in a circular trench, of which the centre is under the highest point of the aerial. Radial wires lead out from the station to various points on the ring of zinc and are soldered to it. If the diameter of the zinc were comparable with the height of the aerial this would form a very good earth connection, but as the expense of so large an arrangement would be considerable the diameter of the circular trench is usually only about 20 metres. The lines of current have therefore to travel through the ground for a considerable distance, and, as True has shown, a good deal of power must thus be lost. A much better "earth" is usually obtained by burying a number of wires corresponding in length and capacity to the aerial itself in radial trenches.

H. True has shown experimentally that with an antenna 75 metres high, and having a flat top in the form of an equilateral triangle, each side being 75 metres long, the greater proportion of the current enters the ground between 50 metres and 90 metres from the point below the centre of the antenna.

The wave-length in this case was 1,000 metres, and the ground water was about 1.5 metres below the surface. The greater the wave-length the further out does the main current enter the earth, and it would appear therefore that the general resistance should be higher for long waves than for short. I find that this conclusion is borne out by Austin's experiments on the resistance of antennas.

Determination of Direction of Radiation.—Though not invariably advantageous, it is sometimes useful to be able to limit the transmission to approximately one direction. Thus a large number of stations at different points might communicate with one another in pairs without interference or the necessity for tuning. It would also occasionally be very useful, especially for maritime purposes, to be able to determine the direction of the station from which a message has come. The two problems are distinct, the latter being, at present at least, the more important. If a ship were able to tell the bearings of a land station from which she is receiving a message it would be an assistance to navigation in thick weather; while, if the bearings of two coast stations could be found simultaneously, the actual position of the ship would be easily calculable by trigonometry.

The Bellini-Tosi "wireless compass," which has been fitted on a number of passenger vessels during the past few years, accomplishes the whole operation with great ease and considerable accuracy. It consists simply of a radiogoniometer receiver (see p. 233) fitted with a pair of triangular aerials. By means of it the bearings of any neighbouring station may be found immediately within one or two degrees. If simultaneous bearings of two land stations are taken, the actual position of the vessel is at once determined.

With Mr Marconi's first system, Hertzian waves were used, which were reflected from parabolic mirrors, as in Hertz's experiments, and of course the radiation was directed as a ray from the mirror. So well does the mirror achieve the purpose of direction that it becomes difficult to maintain communication between the stations, as the slightest movement of the reflector so alters the aim of the ray that it may pass above or below the receiving station without touching it. Wireless telegraphy of this kind would be almost useless at sea on account of the difficulty of keeping the ray directed towards the receiving station. The ray is invisible, and signals can only be received if it strikes the receiver directly. In this it is unlike the beam from a searchlight, which produces readable signals, even though the ray does not strike directly the eye of the observer, but is thrown on a cloud above him. Two vessels can thus communicate by searchlight signalling, though they are invisible to one another below the horizon.

It would thus be very useful to be able to tell the direction from which a signal comes, but of much less general importance to be able to limit the transmission to a given small angle.

Many attempts have been made to obtain directed waves, most of them depending on the expected interference of the waves from two aerials placed half a wave-length apart. If the jigs in both were in the *same* phase, it would appear that the radiation should be zero in a vertical plane through the wires and a maximum in a vertical plane at right angles to this. In 1899 the author commenced experimenting with this idea, but extraneous circumstances prevented the experiments getting beyond the preliminary stage. This was probably the first attempt, however, to obtain directed waves by means of aerial wires, and without the use of reflectors. More recently, the subject has been studied, and patents taken out by

Braun, Artom, Stone, and many others. Professor Braun's work on phase differences between high frequency circuits, undertaken to obtain data for a method of this type, is a masterpiece of experimental and mathematical skill.* Though presenting no great difficulties where the desired direction of transmission is a fixed one, this method would have been impracticable for maritime purposes, particularly in cases where it was advisable to use a wave of considerable length, owing to the excessive size of the apparatus. To find the direction from which the radiation has come would on this system be even more troublesome, as it would involve either a number of fixed aerials, or a fixed one and another movable, so as to accommodate both change of direction and difference of wave-length.

A simpler method † for attaining the same end was found by Mr Garcia in 1900, who used horizontal or inclined aerial wires earthed at one end. These were arranged, so that the effective radiation only took place throughout a small solid angle, and could therefore be directed by altering the direction of the aerials. In a similar manner the direction from which the current was coming could be determined.

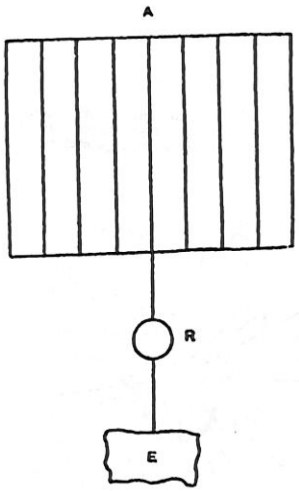


FIG. 130.—DE FOREST'S DIRECTIVE AERIAL, VERTICAL FORM.
A, Grid of Vertical Wires; *R*, Transmitting or Receiving Instrument; *E*, Earth.

In patents applied for on 28th May 1904, Dr de Forest describes two methods by which the direction of the sending station may be determined. The first involves the employment of a large grid of vertical wires which is suspended, so that it may be turned about a vertical axis. The strongest signals are received when the plane of the grid is at right angles to the line joining the stations, and weakest when the plane of the grid is in this line. By taking a few observations with the grid in different positions (orientations), the direction of the line joining the stations can be determined with considerable accuracy.

It was found that by using a grid 15 by 6 feet as aerial and turning about until a maximum strength of current was observed, it was possible to determine within 10° the direction of a station seven miles off.

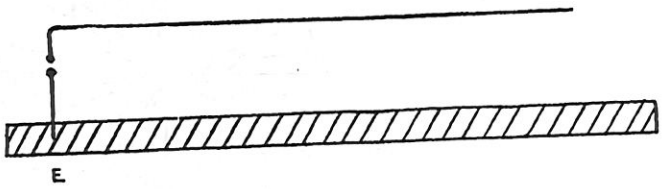


FIG. 131.—DIRECTIVE AERIAL, HORIZONTAL FORM.
The receiver is connected across the gap in the vertical.

For practical purposes this means that if two coast stations about five miles apart were situated favourably with regard to a ship about five miles off shore, they could give the bearings with sufficient accuracy to enable the master to determine his position to within one mile. In foggy weather on a dangerous coast even this degree of accuracy would be of great value, while no doubt, as the method is developed, very much greater exactitude may be looked for in the future.

In another patent of the same date Dr de Forest describes another method of obtaining the direction of motion of the lines of force concerned in transmission. A long horizontal wire is suspended at a short distance above the ground and has a short earth connection in which the receiver is placed. It was observed that a maximum effect was noticeable when the horizontal wire was an extension of the line joining the stations. Thus by turning the wire in a horizontal plane about its vertical part and noting the position of greatest current, it is possible to find the direction of the sending station.

---

* *Electrician*, May 25, 1906, and many earlier dates.
† See letter by F. Galliot, *Electrician*, May 18, 1906.

Either solution of the problem seems applicable directly to practical working.

Dr de Forest attempted to solve the problem of directing the radiation in a somewhat similar manner. In March 1901, and more particularly in a patent of January 1904, he states that an aerial consisting of a short vertical branch and a horizontal part from the top of the vertical one, and a second upward vertical branch from the outer end of the horizontal, sends out most moving lines of force (radiation) on the side of the lower vertical opposite to the horizontal branch and in the direction of the horizontal wire produced.

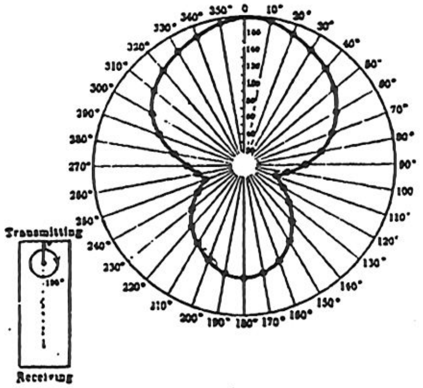


FIG. 132.—CURVE SHOWING OBSERVED CURRENT IN MICROAMPERES AT EARTHED END OF RECEIVING CONDUCTOR UNDER THE CONDITIONS OF DIRECTION SHOWN BELOW.

Transmitting Conductor: Horizontal, rotating from 0 deg. to 360 deg., 1.5 metres above ground. Receiving Conductor: Vertical, fixed; height, 18 metres. Length of Transmitting Conductor, 60 metres, Receiving Conductor, 18 metres. Distance of Transmission, 260 metres. [MARCONI.]

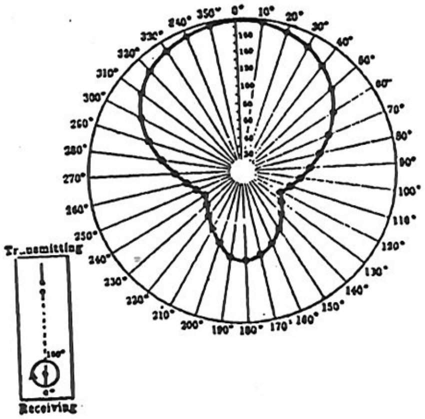


FIG. 133.—CURVE SHOWING OBSERVED CURRENT IN MICROAMPERES AT EARTHED END OF RECEIVING CONDUCTOR UNDER THE CONDITIONS OF DIRECTION SHOWN BELOW.

Transmitting Conductor: Horizontal, fixed, 1.50 metres from ground. Receiving Conductor: Horizontal, rotating from 0 deg. to 360 deg., 1.50 metres from ground. Length of Transmitting Conductor, 30 metres, Receiving Conductor, 30 metres. Distance of Transmission, 225 metres. [MARCONI.].

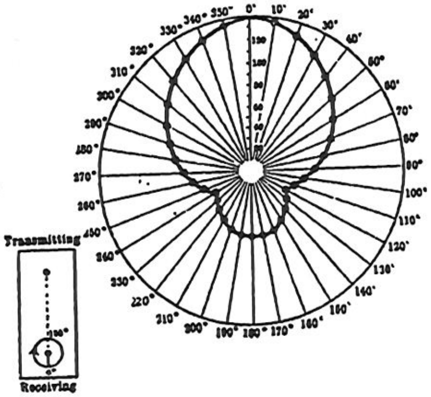


FIG. 134.—CURVE SHOWING OBSERVED CURRENT IN MICROAMPERES AT EARTHED END OF RECEIVING CONDUCTOR UNDER THE CONDITIONS OF DIRECTION SHOWN BELOW.

Transmitting Conductor: Vertical, fixed; height, 44 metres. Receiving Conductor; Horizontal, rotating from 0 deg to 360 deg., 1.50 metres above ground. Length of Transmitting Conductor, 45 metres. Receiving Conductor, 30 metres. Distance of Transmission, 680 metres. [MARCONI.

Messrs Duddell and Taylor experimented in June 1904* with a transmitting aerial of inverted L shape, but their results were not sufficiently definite to indicate the strongly directive action of a horizontal aerial, as found by Mr Marconi.

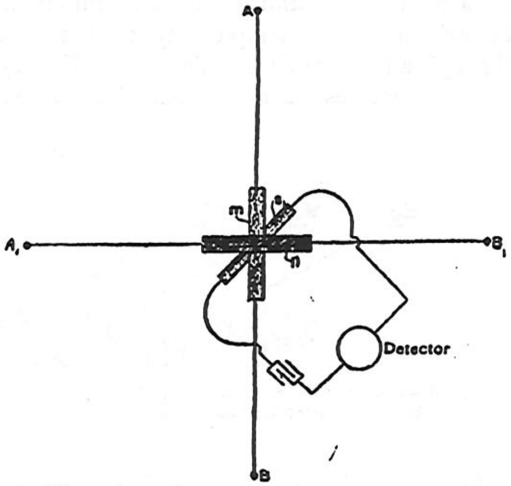


FIG. 135.—BELLINI AND TOSI RECEIVER (RADIOGONIOMETER).
AB, A_1B_1, Bases of Aerials; *m*, *n*, Primaries; *s*, Secondary (movable).

In July 1905 Mr Marconi patented an arrangement in which both transmitting and receiving aerials were horizontal wires pointing in opposite directions. Figs. 132, 133, 134 are taken from Mr Marconi's paper, read before the Royal Society on 22nd March 1906. They show the strength of current radiated in various directions from a horizontal aerial, and also the varying absorptive power of a horizontal receiving aerial when placed at different angles to the incoming waves. In Fig. 132, the transmitting aerial is horizontal and the receiver vertical; in Fig. 133, both are horizontal; in Fig. 134, the transmitter is vertical

---

* *Journal of the Institute of Electrical Engineers*, vol. 35, p. 328.

and the receiver horizontal. His results are of great interest both from practical and theoretical points of view, and have been explained, on the basis of Maxwell's equations, by Professor Zenneck.

Bellini and Tosi.—Commencing as owners of Artom's patents, these inventors have constructed a most elegant and apparently efficient system of directive telegraphy. In its latest form the aerial consists of two equilateral triangles of wire, open for a short distance at the top, and a central vertical wire. At the middle point of the base of each triangle is a short helix, the two forming a rectangular cross. These helices form the secondary winding of a transformer of which the primary is another helix with its axis in a parallel plane, and pivoted at its middle point just below the cross. In order to transmit in any given direction the primary is slewed round into this direction and excited. The cross transformer then analyses the oscillation into two components according to the parallelogram law, and excites the two triangular aerials correspondingly. The resultant of their combined radiation is then a maximum in the direction in which the primary points.

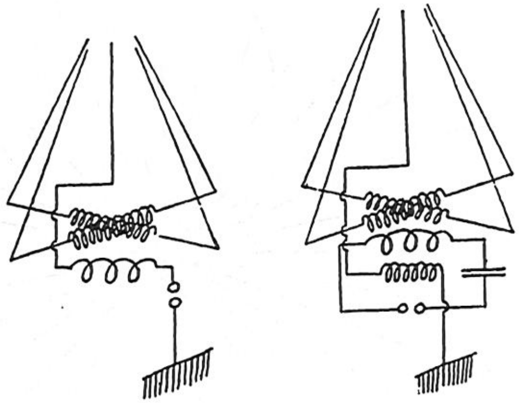


FIG. 136.—BELLINI AND TOSI DIRECTIVE TRANSMITTERS.

A similar explanation is applicable to reception. The primary, now acting as secondary, is slewed round until the current induced in it is a maximum; it then points in the direction from which the waves have come, *i.e.*, towards the transmitter. It has been found possible to thus locate the direction of a transmitting station to within one degree of angle. It should be noted that this type of apparatus may be used to exclude signals coming from directions other than that of the corresponding station.

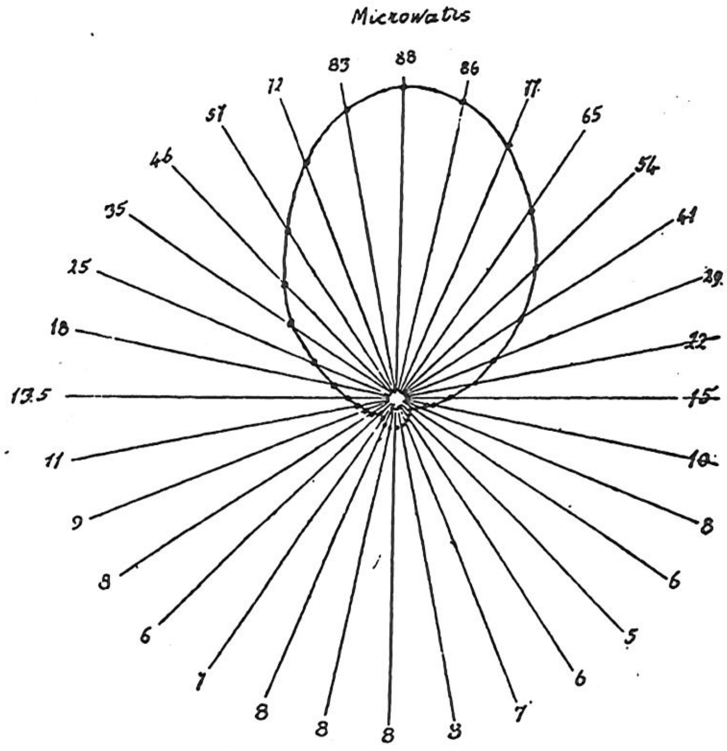


FIG. 137.—POLAR DIAGRAM OF ENERGY TRANSMITTED.

The use of the central vertical aerial is to check entirely the backward radiation. The strength of radiation from the two triangular aerials forms a figure 8 diagram, *i.e.*, it has maxima both forwards and backwards, in a line through the aerials, but the radiation in opposite directions is in opposite phase, hence by superposing radiation from the central aerial in phase with the forward radiation, the backward radiation is annulled and the forward strengthened. The result is that radiation is entirely confined to the forward direction, and shows a maximum in the line of the primary. The simplest type of circuit is shown in Fig. 136, and its radiation diagram in Fig. 137.

Excellent results have been obtained with this system at stations established at Barfleur, Havre, and Dieppe. The positions of stations on the English coast, and of ships in the Channel, have been located by triangulation from two of the French stations with considerable accuracy. This system is now the property of the Marconi Company.

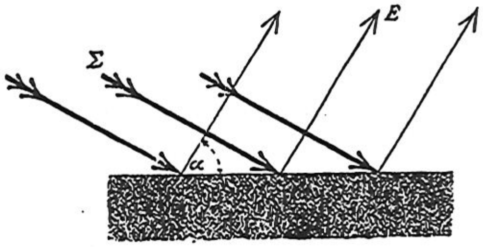


FIG. 138.—PROPAGATION OF WAVES ALONG CONDUCTOR OF HIGH RESISTANCE. *E*, Electric Force; Σ, Average Direction of Energy. [ZENNECK.]

Telefunken Wireless Compass.—To enable ships fitted with ordinary non-directive antennas to determine the bearing of a land station, the Telefunken Company have erected coast stations fitted with a number of radial horizontal antennas which are successively energized at equal time intervals. A distinctive signal is sent out by the north-south antenna, and when he hears this the operator on board ship starts a stop watch graduated in points of the compass. He stops the watch when the signals reach a maximum and reads the bearing directly from the watch.

Theory of Directive Telegraphy.—The action of a horizontal aerial in transmitting and receiving has been most satisfactorily explained by Professor Zenneck, as a corollary to his mathematical theory of the transmission of electric waves along surfaces of different conductivities and dielectric constants. He has shown that where the lines of electric force constituting a wave front pass along the surface of a conductor of high resistance and low specific inductive capacity, such as earth, they become inclined forward, their lower ends being retarded by the resistance of the conductor to which they are attached. Now the maximum effect is produced in a receiving aerial when it is parallel to the lines of force, hence an aerial inclined away from the transmitting station, or what is equivalent, an aerial with a horizontal piece at the top directed away

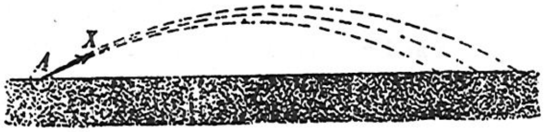


FIG. 139.—PATH OF RADIATION OF ENERGY OVER EARTH'S SURFACE.

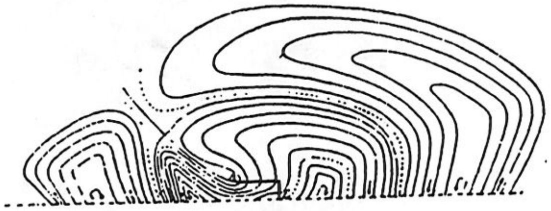


FIG. 140.—WAVES FROM A HORIZONTAL AERIAL ON LAND (K. ULLER).
Showing greater radiation on convex side owing to less dissipation of energy by earth resistance.

from the transmitter, will be more strongly excited than an aerial of any other form; or of the same form in any other position. To explain the directive action of a horizontal aerial in transmitting, he points out that, in general, the wave front at the receiver is inclined forward, and hence the average direction of the flow of energy, being at right angles to the wave front, dips downwards towards the earth at the receiver (Fig. 138). Thus the energy received at a land station comes from high up and was not radiated horizontally from the transmitter, but commenced its course at an upward angle (Fig. 139). Now, a bent antenna with a horizontal portion gives a more powerful radiation in an upward direction away from the bend than would a plain vertical one (Fig. 140), hence the increase of power at long distances obtainable by using a considerable horizontal extension, and hence also the directive effect giving a maximum available radiation in a definite direction.*

Harald von Hoerschelmann (*Jahrbuch*, 5, 1 and 2), in a theoretical investigation, finds that the Marconi bent antenna acts as if there were two vertical antennas, in the plane of the actual antenna, one on either side of the vertical portion, and having currents differing by π in phase. These vertical currents arise only when the ground near the antenna is a comparatively bad conductor. A. Montel has also given a somewhat similar explanation. Marconi's observation, that it is advantageous to place horizontal earth wires under the antenna and in the direction of transmission, thus concentrating the currents in the plane of the antenna, does not enable us to determine whether this explanation or that of Zenneck and Uller is more correct.

---

* J. Zenneck, *Ann. d. Physik*, 23, 5, p. 846, Sept. 1907; *Physikal. Zeitschr.* 1908, No. 2, p. 50; No. 17, p. 553.

CHAPTER XV.

SOME POINTS IN THE THEORY OF JIGS AND JIGGERS.

Properties of Oscillating Motions.—In order that we may start with a clear idea of the nature and properties of an oscillating motion, whether electrical or mechanical, I quote (with the kind permission of the author and the publishers) the following concise description of the simplest form of periodic motion given by Professor Gibson in his "Elementary Treatise on Graphs."[*] It should be noted that though the motion of a point to and fro in a straight line is all that is mentioned, the distance x of this point from the fixed point which is chosen as origin may represent any single valued quantity such as voltage or current, and thus the one set of equations will serve to represent any simple to-and-fro motion, whether mechanical or electrical. To make the matter still clearer we may suppose that x represents the ordinate of a curve which gives the variations of the electrical quantity with time.

"**Simple Harmonic Motion or Sine Wave.**—When a point is moving in a straight line in such a way that at time t its distance x from a fixed point O on the line is given by the equation

$$x = a\cos(nt+\alpha),\text{ or } x = a\sin(nt+\beta) \quad . \quad . \quad . \quad (1)$$

the point is said to describe a simple harmonic motion.

---

[*] London : Macmillans.

"The motion is obviously vibratory, or to and fro. The point moves first in one direction to the distance a from O, then back through O to a distance a on the other side, then returns towards O, and so on. The greatest distance from O that the point reaches, namely, a, is called the *amplitude* of the motion.

"As t increases from O to $\frac{2\pi}{n}$ (or from t_1 to $t_1+\frac{2\pi}{n}$ where t_1 is any value of t) the point makes one complete to-and-fro motion, $\frac{2\pi}{n}$ is therefore called the *period* of the motion. The reciprocal of the period, namely $\frac{n}{2\pi}$, is sometimes called the *frequency* of the motion. If T is the period and p the frequency, then

$$\mathrm{T} = \frac{2\pi}{n};\ p = \frac{1}{\mathrm{T}} = \frac{n}{2\pi};\ n = \frac{2\pi}{\mathrm{T}} = 2\pi p.$$

"The function $a\cos(nt+\alpha)$, or $a\sin(nt+\beta)$, is frequently called a simple harmonic function of t; its graph, that is the cosine curve or the sine curve, is called a simple harmonic curve. The function is of great importance in all branches of physics.

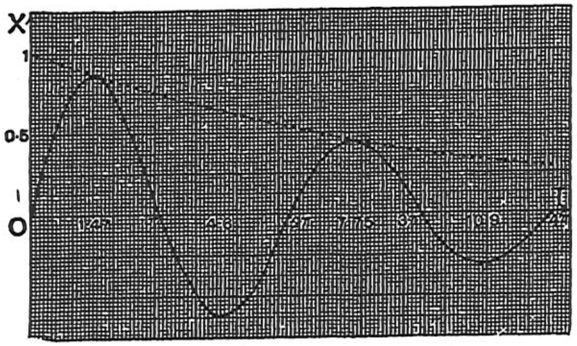


FIG. 141.

"The function of t given by the equation (k positive)

$$x=ae^{-kt}\cos(nt+\alpha) \text{ or } x=ae^{-kt}\sin(nt+\beta) \quad . \quad . \quad (2)$$

is sometimes called a simple harmonic function with decreasing amplitude. The coefficient ae^{-kt} of the cosine or sine is a function of t, which decreases as t increases. Physically the equation represents what is termed a *damped* vibration.

"Fig. 141 is the graph of

$$x=e^{-\frac{t}{10}}\sin t \quad . \quad . \quad . \quad . \quad (3)$$

and gives some idea of the nature of the function. Two waves are shown, but after a period of sin t the height becomes very small. Thus, when $t=10\pi+\frac{\pi}{2}$, we find

$$x=e^{-3.30}\sin\frac{\pi}{2}=0.037.$$

"The dotted curve is the graph $e^{-\frac{t}{10}}$ which touches the other graph near the crests of the waves; at the first crest $t=7.75$. The hollows (the minimum values of x) are given by $t=4.6$ and $t=10.9$.

"The amplitude of the function (2) when t has any value t_1 is ae^{-kt_1}; when t has increased by T (where T is the period, $\frac{2\pi}{n}$, of the circular function) the amplitude has decreased to $ae^{-k(t_1+\mathrm{T})}$. The ratio of the first to the second of these amplitudes is—

$$ae^{-kt_1} : ae^{-k(t_1+\mathrm{T})} \text{ or } e^{k\mathrm{T}}.$$

The Napierian logarithm of this ratio, namely kT, is called the *logarithmic decrement* of the amplitude per whole period."

Turning now to more technical mathematics, we have firstly, as is usual in the theory of electricity, an investigation of Lord Kelvin's to consider. The discharge of a condenser had been studied experimentally by Henry and others when Lord Kelvin attacked the problem mathematically, and gave a solution which accorded entirely with the results of observation. For the benefit of readers to whom mathematical language does not appeal, I may explain that the chief results arrived at are as follows:—

A conductor is supposed, charged, and suspended above the earth by insulating supports. It is then suddenly connected to the earth by a wire. It is shown that a discharge takes place which is unidirectional and slow if the ratio of the inductance of the wire to the capacity and resistance of the system is below a certain value, and oscillatory if this ratio is above the critical value. The period, amplitude, and damping of the oscillatory discharge are calculated, and the amount of work done, on the supposition that there is no radiation of electrical energy, but that all is dissipated as heat in the conductors. The values of the current and voltage at any moment of the discharge are also calculable from the equations given. With the capacities and inductances usually available, the oscillations of the current are of such high frequency as to constitute a jig. It is not, however, in the least necessary that an oscillatory current should have a high frequency. Mr J. H. Gray,* for example, has shown how to produce oscillatory currents having a period of about a second and a half by using large inductance and capacity in the circuit.

Let us now consider shortly Lord Kelvin's solution of the problem, which he has kindly given me permission to reproduce:—

"Let C be the capacity of the electrified body in electromagnetic measure, Q_0 its charge, and let it be suddenly connected to the earth by a wire of resistance R, the inductance of which is L. At a given moment t, the charge of the conductor is Q, and its voltage $\gamma=\frac{\mathrm{Q}}{\mathrm{C}}$, which gives the equation for the voltage—

$$\gamma=\frac{\mathrm{Q}}{\mathrm{C}}=\mathrm{L}\frac{di}{dt}+\mathrm{R}i \quad - \quad - \quad - \quad (1)$$

from Ohm's law and the definition of inductance.

---

* *Electrical Engineer*, August 19, 1892.

"Now the current $i = -\frac{dQ}{dt}$, hence equation (1) may be written in the form

$$\frac{d^2Q}{dt^2} + \frac{R}{L}\frac{dQ}{dt} + \frac{Q}{CL} = 0 \quad - \quad - \quad - \quad (2)$$

The general integral of this equation is—

$$Q = Ae^{\rho t} + A'e^{\rho' t},$$

ρ and ρ' being the roots of the quadratic equation,

$$\rho^2 + \frac{R}{L}\rho + \frac{1}{CL} = 0, \quad - \quad - \quad - \quad (3)$$

which gives

$$\rho = -\frac{R}{2L} \pm \sqrt{\frac{R^2}{4L^2} - \frac{1}{CL}},$$

Reducing the fractions under the radical sign to a common denominator, we see that, according as $L \lesseqgtr \frac{R^2C}{4}$, these roots are real or imaginary. The constants A and A′ are determined by the condition that for $t = 0$, we have $Q = Q_0$, *i.e.*, the initial charge, and $i = 0$, which gives $0 = A\rho + A'\rho'$.

"If the roots of the equation (3) are real, then representing by α the radical $\sqrt{\frac{R^2}{4L^2} - \frac{1}{CL}}$,

$$\left.\begin{aligned} Q &= Q_0 e^{-\frac{Rt}{2L}}\left[\left(\tfrac{1}{2} + \frac{R}{4\alpha L}\right)e^{\alpha t} + \left(\tfrac{1}{2} - \frac{R}{4\alpha L}\right)e^{-\alpha t}\right] \quad - \\ i &= \frac{Q_0}{2\alpha LC}e^{-\frac{Rt}{2L}}(e^{\alpha t} - e^{-\alpha t}) \quad - \quad - \quad - \end{aligned}\right\}(4)$$

When the roots are imaginary we may still take the integral in the same form and replace the constants by their imaginary values. Putting $\alpha' = \sqrt{\frac{1}{CL} - \frac{R^2}{4L^2}}$, we get then

$$\left.\begin{aligned} Q &= Q_0 e^{-\frac{Rt}{2L}}\left[\cos \alpha' t + \frac{R}{2\alpha' L}\sin \alpha' t\right] \quad - \quad - \\ i &= \frac{Q_0}{\alpha' LC}e^{-\frac{Rt}{2L}}\sin \alpha' t \quad - \quad - \quad - \end{aligned}\right\}(5)$$

"The nature of the discharge is very different according as the solution is given by equations (4) or equations (5). In the first case the discharge is continuous. The current begins by being zero, passes through a maximum, and then decreases to zero. The maximum is at the time determined by the condition $\frac{di}{dt} = 0$, or

$$\left(\frac{R}{2L} - \alpha\right)e^{2\alpha t} = \frac{R}{2L} + \alpha,$$

which gives

$$t = \frac{1}{2\left(\frac{R^2}{4L^2} - \frac{1}{CL}\right)^{\frac{1}{2}}} l. \frac{\frac{R}{2L} + \sqrt{\frac{R^2}{4L^2} - \frac{1}{CL}}}{\frac{R}{2L} - \sqrt{\frac{R^2}{4L^2} - \frac{1}{CL}}}.$$

"In the second case the values of Q and of i are given by the periodic functions; the conductor takes alternately charges in contrary directions, and the wire is the seat of alternating currents.

"*Period and Frequency.*—The times of maxima and minima of charge correspond to $i = 0$, that is to say, to

$$\sin \alpha' t = 0, \qquad \text{or} \qquad \alpha' t = n\pi.$$

"The oscillations of the discharge are therefore regular, and the value of the complete period T is

$$T = \frac{2\pi}{\alpha'} = \frac{2\pi}{\sqrt{\frac{1}{CL} - \frac{R^2}{4L^2}}}$$

Hence the frequency $n = \frac{1}{T} = \frac{\sqrt{\frac{1}{CL} - \frac{R^2}{4L^2}}}{2\pi}$, or if R be small in comparison to L and C, $n = \frac{1}{2\pi\sqrt{CL}}$.

"*Damping.*—The values of the alternate maxima of charge are

$$+Q_0,$$
$$-Q_0 e^{-\frac{R\pi}{2L\alpha'}}$$
$$+Q_0 e^{-\frac{2R\pi}{2L\alpha'}}$$
$$-Q_0 e^{-\frac{3R\pi}{2L\alpha'}}, \text{ \&c.}$$

They decrease, therefore, like terms of a geometrical progression, the ratio of which is $e^{-\frac{R\pi}{2La'}}$.

"The maxima of the intensity of the current in the two directions correspond to $\frac{di}{dt}=0$, which gives

$$\tan a't=\frac{2La'}{R},$$

or

$$\sin a't=\pm a'\sqrt{CL};$$

They are still equidistant, separated by a semi-period $\frac{\pi}{a'}=\frac{T}{2}$, and succeed the periods at which the current is zero, by the time θ, defined by the smallest angle which satisfies the condition

$$\sin a'\theta=a'\sqrt{CL}.$$

"The values of the maxima of current are successively

$$I_1=+\frac{Q_0}{\sqrt{CL}}e^{-\frac{R\theta}{2L}},$$

$$I_2=-\frac{Q}{\sqrt{CL}}e^{-\frac{R}{2L}\left(\theta+\frac{\pi}{a'}\right)}=-I_1e^{-\frac{R\pi}{2a'L}},$$

and so on; they also decrease in geometrical progression.

"Disregarding the sign, the total quantity of electricity put in motion is

$$Q_0\left(1+2e^{-\frac{R\pi}{2La'}}+2e^{-\frac{2R\pi}{2La'}}+\ldots\right)=Q_0\frac{1+e^{-\frac{R\pi}{2La'}}}{1-e^{-\frac{R\pi}{2La'}}}.$$

"This total mass is the greater the nearer the quantity $e^{-\frac{R\pi}{2La'}}$ is to unity, that is, the greater the factor $\frac{2La'}{R}$, or the greater is the ratio $\frac{L}{CR^2}$, the original charge Q_0 being given."

Hence inductance prolongs while resistance shortens the jig.

Transformers.—The equations for the mutual interaction of two circuits may be obtained in a somewhat

similar way. For each circuit we have in addition to the terms of the form $L\frac{di}{dt}$, Ri, E; a term $M\frac{di_1}{dt}$ representing the action of the other circuit on the one considered. We have thus two simultaneous equations to solve. For transformers of very few turns, in which the electric induction (as opposed to the magnetic induction) is negligible, such equations give an approximate solution even with jigs; but if there is a considerable number of turns in either coil of the transformer, as in some types of jigger, the dielectric induction between the layers must be taken into account as well as the magnetic induction between the coils.

From a theoretical point of view Lord Rayleigh has indicated the importance of electrostatic capacity in the construction of transformers for high frequency currents, and Mr Tesla has recognised its influence in practice, the form of the secondary winding of his H.F. transformer (Fig. 16, p. 26) being very like Fig. 142 (below).

In 1898, knowing the author's experience in electrical research, Mr Marconi asked him to assist in the development of his system. The problem which in particular required solution at that time was the production of a receiving transformer. Attempts had previously been made to construct one, but without any lasting success; and the direct connection of the coherer to the earth and aerial wires was still the method in use.

After a few weeks' work transformers were constructed which not only obviated the difficulties caused by the gradual collection of atmospheric electricity on the aerial, but also greatly increased the sensibility of the receiver, and later on made tuning possible.

A short research on the part played by the capacity of the adjacent layers of insulated wire which formed the windings of the transformer, showed that the condenser formed by two short layers of very fine wire, wound one on top of the other, had sufficient capacity to carry the whole jig current received without the aid of a conducting connection between them. It was clear, therefore, that capacity must play an extremely important rôle in the internal action of the transformer, that, in fact, the electric lines of force of the primary must be considered as well as the magnetic lines.

By consideration of the electric and magnetic induction between the primary and secondary coils of a small transformer, consisting of only two layers of equal length, it may be shown that during a complete alternation of the current the electric lines of force of the primary, and consequently the current induced by them, are mainly in opposition to the E.M.F. resulting from the varying magnetic induction due to the primary current. It was clearly advantageous to give the secondary some other shape so that the electrically and magnetically induced currents in the secondary might be brought nearly into coincidence.

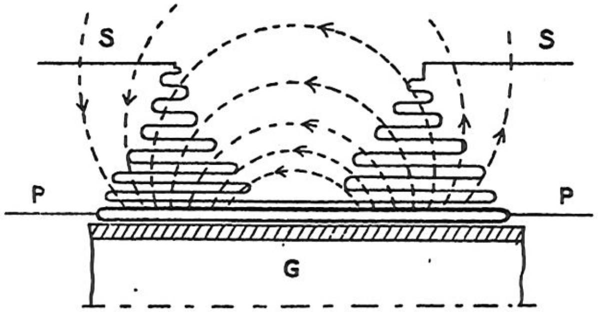


FIG. 142.—HALF SECTION OF RECEIVING TRANSFORMER (JIGGER), DESIGNED TO UTILISE ELECTROSTATIC INDUCTION.

P, Primary in two Parallel Layers; *S*, Secondary in Layers of Diminishing Length; *G*, Glass Tube.

[*N.B.*—Layers of wire are shown as full lines, and not as rows of dots, which would actually represent them.] Dotted lines show direction of electric force at time of maximum.

One way in which this was accomplished is shown in Fig. 142. The dotted lines indicate the direction of the electric force between the ends of the primary at times when it is a maximum, and indicate how the form of the secondary takes advantage of it.

In another form the secondary is wound on one half of the primary only, the other half being under the first and thus screened from the secondary. The explanation is the same in both cases.

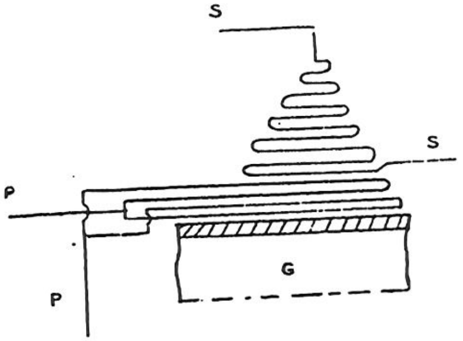


FIG. 143.—HALF SECTION OF RECEIVING TRANSFORMER (JIGGER).

P, *P*, Primary in Two Double Layers, Earth Ends next Glass Tube; *S*, *S*, Secondary; *G*, Glass Tube.

The author then suggested the form shown in Fig. 139.

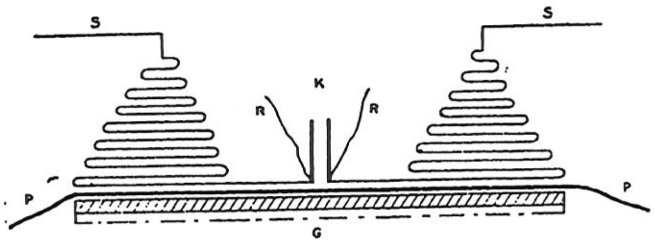


FIG. 144.—HALF SECTION OF RECEIVING TRANSFORMER WITH SPLIT SECONDARY.

P, *P*, Primary; *S*, *S*, Secondary; *K*, Condenser; *R*, *R*, Leads to Relay Circuit; *G*, Glass Tube.

The object of placing the condenser in the middle of the secondary instead of at one end, as had been previously the custom, was to permit of both ends of the secondary being connected directly to the coherer terminals so that the coherer should be at the position where maximum voltage is developed. This arrangement appears to have been adhered to by the Marconi Company. Measurements, in which the author was not directly concerned, of the lengths of the secondaries of successful jiggers showed that in order to obtain the best results it was necessary to give the length of the secondary a definite relation to the length of the aerial, thus making revibration possible.

In other forms of winding, as shown in Fig. 143, the electric and magnetic inductions assist one another, and of course the length of the secondary is such that the receiver circuit has the same frequency of vibration as the aerial.

A successful receiving jigger is thus a resonating transformer designed so that the electric induction assists, or at least is not in opposition to, the current produced by change of magnetic induction.

Fig. 27, page 43, shows a direct coupled primary and secondary in which the central part of the single layer forms the primary, and is also a part of the secondary. In this case the capacity between primary and secondary is practically negligible, but there is a direct conducting connection instead.

The construction of transmitting transformers is somewhat simpler, the currents dealt with being much larger, and high efficiency not so essential. Those used by most companies are simply modifications of Mr Tesla's original high frequency resonating transformer. It is needless to go into their slight variations in detail. The most interesting is Mr Tesla's most recent pattern, the design of which is shown in Chapter XVII. It will be noticed that the end of the secondary which attains high potentials is at the centre of the disc, and is thus separated by the whole radius of the disc from the earthed end. Thus the difference of potential between adjacent turns of the secondary is comparatively small, and very high voltages may be obtained without difficulties due to faulty insulation or to capacity.

Rate of Sparking—Number of Jigs per Second.—Ordinary methods of transmission involve the production of a number of sparks per second. Each spark represents a train of gradually decreasing oscillations of high frequency—what we have called a jig, in fact—and is associated with a definite amount of energy, which is the same for every jig. If, therefore, the apparent or integral current due to the passage of a succession of jigs through the measuring instrument be increased by increasing the number of jigs per second without altering the total energy of each, we should find that the current registered is proportional to the square root of the number per second.

If we double the number of jigs per second we double the watts, or activity; we do not, however, double the current, as shown by an instrument indicating R.M.S. current, but merely increase it in proportion to the square root of the number per second, for the activity is proportional not to the current directly, but to its square.

That this has been proved experimentally to be the case is shown by the following extract from an exceedingly important paper by Messrs Duddell and Taylor, communicated to the Institution of Electrical Engineers in 1905:—

> "*Effect of the Rate of Sparking.*—With the strongly coupled method of transmitting the ammeter indicated a R.M.S. current in the transmitter aerial of 2.31 amperes for a rate of sparking of 42 per second; an increase in the speed of the interrupter to give 67 sparks per second, keeping the spark length constant, increased the R.M.S. current to 2.83 amperes. Thus, although the rate of sparking was changed in the ratio of 1 : 1.60, the current in the aerial only altered in the ratio of 1 : 1.22. Using the weak method of coupling, a similar result was obtained. In this case an increase in the spark rate in the ratio 1 : 1.67 caused the current to increase in the ratio 1 : 1.30. It is to be noted that in both cases the R.M.S. current in the aerial varied approximately proportional to the square root of the rate of sparking. This also applies to the current in the receiver aerial. If we now

wish to consider how the R.M.S. current in the aerial during the train of oscillations produced by each interruption of the current of the induction coil is affected by the rate of sparking, we must multiply the observed currents by the square root of the ratio of the whole time between one spark and the next to the time the rate of oscillation lasts. Assuming that the time each individual train of oscillations lasts is unaffected by the spark rate, we see that the R.M.S. current in the transmitter or receiver aerial produced by each interruption of the coil current, was practically independent of the spark rate."

Lieutenant Tissot has most kindly permitted me to quote the following from a paper communicated by him to the Institution of Electrical Engineers in January 1906:—

"My experimental observations also showed that if the number of interruptions is made to vary from n to n' per second, the effective value of the current received by the aerial varies in the ratio of $\sqrt{n}$ to $\sqrt{n'}$. This result, which appears in accord with the observations of Duddell and Taylor, is readily capable of interpretation by reasoning as follows. Let

I denote the reading on a hot-wire ammeter put in series at the bottom of the transmitting wire.
A = the amplitude of the current in the aerial.
T = the period.
y = the decrement of the oscillation.
n = number of interruptions, that is of wave trains per second.

"By a simple integration we then obtain for the fundamental wave—

$$I^2=\frac{nA^2}{4y}\cdot\frac{4\pi^2}{4\pi^2+y^2}\cdot T.$$

"Since the factor $\frac{4\pi^2}{4\pi^2+y^2}$ is almost equal to unity, it is clear that the energy transmitted by a single wave train, which is proportional to A^2, is given by a relation of the form $W_o=KA^2=K'\frac{I^2}{n}$ (K and K' being constants). In

the same manner the energy received for a single wave train is easy to compute, if one assumes that the detector completely absorbs the energy. If an effective current i is obtained with n interruptions, that is, with n trains per second, then the equation $W=\frac{pi^2}{n}$ expresses the energy received for a single wave train p being the resistance of the measuring instrument (in this case the bolometer), when the number of interruptions varies from n to n', i varies from i to i', and $\frac{i'^2}{i^2}=\frac{n'}{n}$, whence $\frac{i'}{i}=\frac{\sqrt{n'}}{\sqrt{n}}$."

Absorption of Energy by a Secondary Circuit.—Consider two circuits A and B in one of which, A, a uniform alternating current is maintained by an external agency. Let the resistance of B be R, the inductance L, and the capacity C, and let the circuits be weakly coupled by mutual induction or otherwise, and let the natural frequency of B be that of the current in A.

When R is large we get only forced vibrations in B, and the electrical energy it absorbs from A is entirely spent in overcoming resistance and in back radiation; it is therefore dissipated, none being stored in B.

As R is decreased—the capacity and inductance being maintained—there is a point at which it becomes possible for the circuit to vibrate freely,* and when $4L>R^2C$ some of the energy absorbed is stored as oscillatory current, the proportion thus stored being greater as the ratio $4L/R^2C$ increases.

If $R=0$, all the energy absorbed remains in the electrical form.

Resonance and Resonance Curves—Uniform H.F. Applied Voltage.—When a uniform alternating E.M.F., e, of frequency n_1 cycles per second, acts on a circuit containing capacity and inductance, the amplitude of the induced current, γ, is given by the equation—

---

*.See p. 241.

$$\gamma_0 = \frac{e_0}{\sqrt{R^2 + \left(2\pi n_1 L - \frac{1}{2\pi n_1 C}\right)^2}}.$$

This gives a maximum for current, γ_0, when $2\pi n_1 L = 1/2\pi n_1 C$, an equation which may otherwise be written $n_1 = 1/2\pi\sqrt{LC}$. But this is also the free frequency of oscillation of a circuit having capacity C, and inductance L, which is only slightly damped. Hence with negligible damping the maximum current is induced when the frequency of the impressed E.M.F. is the same as the free frequency of the secondary circuit. The circuit is then said to *resonate* or revibrate to the impressed alternating voltage, and it is said to be *tuned* to the frequency of the latter.

If, however, the damping of the circuit is not negligible, *i.e.*, if there is resistance, the free frequency of the circuit becomes $n_2 = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - d^2}$, where d is the damping factor $d = R/2L$. Hence for the condition of maximum current, *i.e.*, resonance, we have now $n_1 = n_2\sqrt{1 + \left(\frac{d^2}{2\pi n_2}\right)}$, *i.e.*, the maximum current exists when the impressed frequency and the free frequency of the circuit are somewhat different.

It is thus clear that maximum resonance does not necessarily coincide with equality of frequency.

Amplitudes.—The expressions which give the amplitudes of the current and voltage for resonance are $\gamma_0 = e_0/2Ld$ and $v_0 = 2\pi n e_0/2d$. Thus the amplitudes of the induced current and voltage continually increase as the damping of the oscillatory circuit is reduced. The current and voltage cannot, however, increase indefinitely, since with increasing amplitude there is a rapidly increasing waste of energy, owing to resistance, which ultimately becomes equal to the energy supply from without, since the former is proportional to the square of the current, while the latter only varies as the first power, and since there is also radiation.

Resonance Curves and Damping.—In order to determine more fully the action of an external *steadily alternating E.M.F.* on a circuit capable of free vibration, we may proceed in either of two ways. Either (1) we may vary the frequency of the impressed E.M.F., or (2) we may keep this constant, and vary the natural frequency of the circuit by altering the product of its inductance and capacity. We shall consider the latter case only, and we shall also suppose the capacity only to be varied, since variation of the inductance would in general cause a

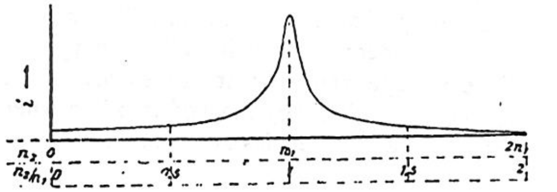


FIG. 145.—CURRENT IN SECONDARY CIRCUIT FOR DIFFERENT RATIOS BETWEEN SECONDARY FREE FREQUENCY, n_2, AND THAT OF PRIMARY, n_1.

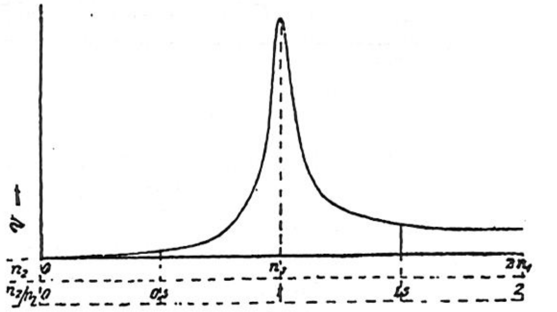


FIG. 146.—VOLTAGE CURVE CORRESPONDING TO FIG. 145.

variation in the resistance of the circuit, and would thus add a further complication.

Slightly Damped Circuits.—Figs. 145 and 146 show the variation of the induced current and voltage when the frequency of the impressed E.M.F. is constant; the logarithmic decrement δ per half period being in this case $=0.04$. The voltage and current curves are not exactly similar, except in having very marked maxima when the impressed and natural frequencies are practically equal.

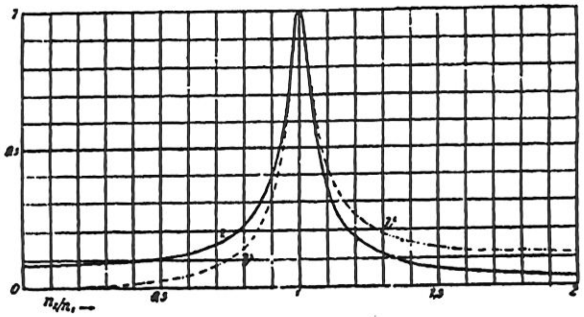


FIG. 147.—CURVES OF FIGS. 145 AND 146 REDUCED TO SAME MAXIMUM AND PLOTTED WITH n_2/n_1 AS ABSCISSÆ.

Instead of plotting the frequency as abscissa, it is sometimes convenient to take, instead, the ratio n_2/n_1; and by taking the maximum values of induced voltage and current as each equal to unity the curves may be more easily compared (see Fig. 147). In this form the curve is sometimes called a "Damping Curve."

The alteration in the form of the current curve caused by variation in the damping is shown in Fig. 148. The greater the damping (or logarithmic decrement), the flatter the curve and the less is the maximum current. Hence the importance of having as little resistance as possible in the receiving circuit when sharp tuning is required, or when very weak signals have to be detected.

Sharpness of Tuning.—If a small change in the frequency of the impressed alternating voltage causes the induced current to fall off very rapidly on both sides of the resonance point, the tuning is said to be "sharp." This condition is graphically expressed by saying that the radius of curvature of the resonance curve at the point of resonance

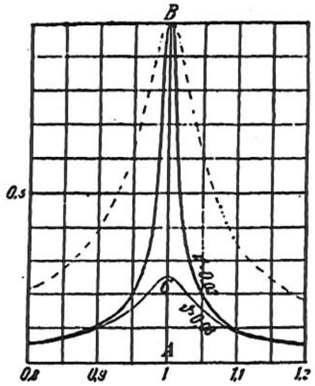


FIG. 148.—EFFECT OF DAMPING ON FORM OF RESONANCE CURVE.

(*i.e.*, maximum ordinate) must be small. Algebraically, if ρ be the radius of curvature, $\frac{1}{\rho}=\frac{1}{\left(\frac{\delta}{\pi}\right)^2}$, or $\delta=\pi\sqrt{\rho}$ in the curve of Fig. 148.

Heavily Damped Circuits.—In the case of circuits which contain considerable resistance, and are, consequently, heavily damped, *e.g.*, $\delta=0.1$ and upwards, the resonance (*i.e.*, maximum current) frequency is very appreciably different from the free frequency of the circuit; and at the same time the voltage maximum differs in frequency from the current maximum.

Coupled Circuits.[*]—Some standard types of circuit are shown in Chapters VIII., XIII., and XVII. The possible variants on these are practically innumerable as may be seen by inspection of the patents of Fessenden, Stone, Poulsen, and others. The chief considerations in deciding on the best type of coupling between the generating circuit and the aerial are: (1) the rate of transmission of energy to the aerial, and (2) the type of oscillation excited in it. These two considerations are to some extent antagonistic, at least in the case of spark stations. The difference between the spark and "arc" is that in the former the whole energy available for each train of waves is limited to what has been stored in the apparatus before the spark occurs, while in uniform current, or arc systems, energy is being continually supplied throughout every phase of the current.

---

[*] The mathematical theory of Coupled Circuits and Resonance was first given by V. Bjerknes in *Wiedemann's Annalen*, 44, 74, 1891, and 55, 121, 1895.

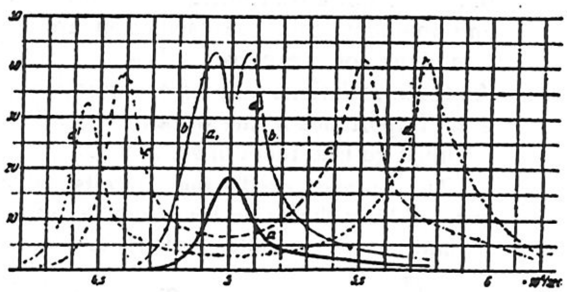


Fig. 149.—Resonance Curves of Spark Circuit, Double "Beat" Frequency of Induced Current.

a, *b*, *c*, . . . are resonance curves in which coupling between the circuits is progressively stronger. The damping is small here. Notice that the closer the coupling the greater the difference between the resonance frequencies, and thus the more rapid the beats.

Beat Currents.—In spark systems it is thus found that though the natural free frequencies of the coupled circuits may be the same, their mutual interaction may cause the energy to sway to and fro between them. The wave train emitted from the aerial is thus a series of beats, as in Fig. 150. This result has been demonstrated both experimentally and theoretically, and it has been shown that the character of the "beat" depends mainly on the relative resistances, or damping, and on the coupling of the circuits.

Now a wave train which "beats" can be analysed, both experimentally and mathematically, into two component wave trains of nearly, but not quite, the same frequency. The radiation from a spark station is, therefore, apt to have apparently two unequal frequencies, which renders sharp tuning to any given wave-length impossible. To avoid this double frequency, it is necessary either to reduce the action of one circuit on the other to a minimum, *i.e.*, to make the coupling weak by reducing the mutual inductance, or to increase the damping in the primary relative to that in the aerial to such an extent that the oscillating current in the latter is free from interaction with the primary for the greater part of its duration. The choice of the best coupling between the aerial and generating circuits is, therefore, a matter of compromise which depends on whether sharp tuning or large amplitude of oscillation is desired.

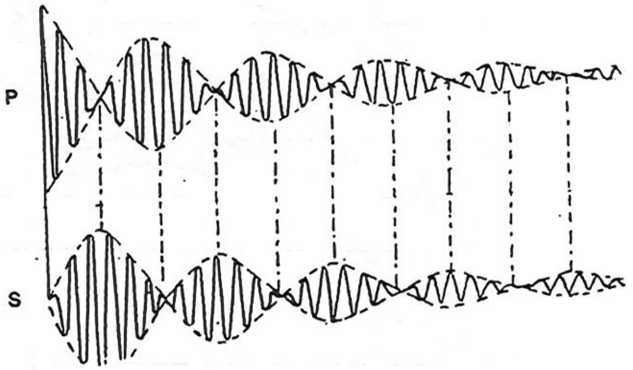


Fig. 150.—"Beating" Wave Trains, each Analysible into Two Trains of Different Frequency.

P, Primary; *S*, Secondary.

Coefficient of Coupling.—The coupling k is defined mathematically as $k=\frac{M}{\sqrt{L_1L_2}}$, where M is the mutual inductance of the circuits and L_1, L_2 their respective self-inductances.

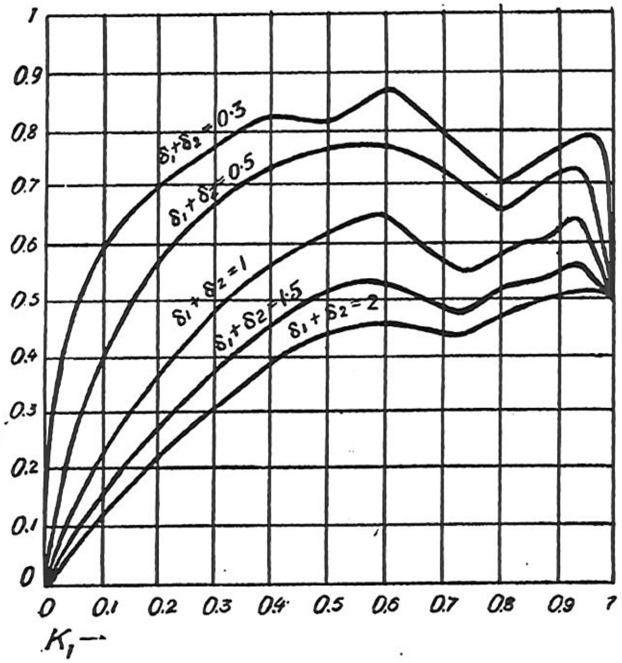


FIG. 151.—RELATION OF ENERGY TRANSMISSION FROM PRIMARY TO SECONDARY WITH COUPLING, K_1, AND SUM OF LOGARITHMIC DECREMENTS ($\delta_1+\delta_2$) PER PERIOD, OF THE CIRCUITS. From Experimental Results. (DRUDE.)

Coupling.—There are four general cases of transmission of energy from a primary to a secondary circuit tuned to the same frequency:—

(1) *Very Loose Coupling*, in which the secondary current has no appreciable reaction on the primary, *e.g.*, (*a*) a transmitter and distant receiver; (*b*) any oscillating circuit and a wave-meter at a proper distance from it. In both of these cases the receiver or secondary circuit should have no appreciable influence on the primary.

(2) *Loose Coupling*, in which there is a slight reaction, causing changes in the damping of the oscillations in both primary and secondary, but practically no other alteration. The decrement of the less damped is increased, and that of the more damped decreased, *i.e.*, the decrements approximate towards one another.

(3) *Close Coupling* such as is generally used between the circuits of a transmitter. In this case the decrements and frequencies of the oscillation are all altered by the interaction of the currents, beat currents being produced. As these variations may be comparatively large, and are of great importance in the working of ordinary spark stations, we must go into them in some detail.

Two tuned oscillating circuits which before being coupled have the same frequency N, and have decrements δ_1 and δ_2 (per whole period), are closely coupled,, *i.e.*, $k=\frac{M}{\sqrt{L_1L_2}}=0.1$ or more. Then $k^2>\left(\frac{\delta_1-\delta_2}{2\pi}\right)^2$, and if κ be defined as the degree of coupling, $\kappa^2=k^2-\left(\frac{\delta_1-\delta_2}{2\pi}\right)^2>0$.

That these relations are true in general may be seen from consideration of the fact that δ_1 and δ_2 are usually small fractions, hence the numerator of $\left(\frac{\delta_1-\delta_2}{2\pi}\right)^2$ is very small. It is equally true if δ_1 and δ_2 are very nearly equal to one another whatever be their actual magnitudes. Thus, as a rule for close coupling, κ is nearly equal to k. Under these circumstances there appear, in both circuits, two new oscillations having frequencies N′ and N″, and decrements δ' and δ'':—N′ and N″ being respectively greater and less than N.
]

These new "beat" frequencies are given by the equations :—

$$N' = N/\sqrt{1-\kappa}, \text{ and } N'' = N/\sqrt{1+\kappa};$$

or in terms of the wave-length,

$$\lambda' = \lambda\sqrt{1-\kappa}, \text{ and } \lambda'' = \lambda\sqrt{1+\kappa}.$$

Thus the closer the coupling, *i.e.*, the greater κ is, the more do N′ and N″ differ from the original free frequency N of the circuits. These equations are true for circuits containing no gaseous section (spark-gap), but are only approximate if there is a gap in the primary, since the decrement due to a gaseous section varies with the current at the moment.

The decrements of the apparent oscillations N′, N″, are given by the equations :—

$$\delta' = \frac{\delta_1+\delta_2}{2} \cdot \frac{N'}{N} = \frac{\delta_1+\delta_2}{2} \cdot \frac{\lambda}{\lambda'},$$

$$\delta'' = \frac{\delta_1+\delta_2}{2} \cdot \frac{N''}{N} = \frac{\delta_1+\delta_2}{2} \cdot \frac{\lambda}{\lambda''},$$

if there is no gap in circuit. Here the oscillation with greatest wave-length λ″ is the least damped. If there is a gap in the primary, the reverse is true, and in general it is the oscillation of greatest wave-length which is most damped.

(4) *Shock Excitation.*—Wien discovered, in 1906, that if the primary current be very much damped by using an extremely small gap, the electrodes of which cool the spark so rapidly that its resistance rises very rapidly (and the damping increases) as the current falls, and the spark goes out at once, an entirely different type of action takes place. Thus by gradually decreasing the gap to a small fraction of a millimetre, he found that the two beat frequencies N′ and N″ disappeared, and that the current in the secondary had instead its own free frequency N, only.

The equations given above do not hold good in this case, for the spark having died out at the end of one or two oscillations, the gap becomes non-conductive, and no further current is possible in the primary until the next discharge takes place. There is therefore no swaying to and fro of the energy between primary and secondary, the whole having been delivered to the secondary with a rush at the commencement. In the Lepel system (see page 211) in which this principle is embodied, δ_1 is very large, δ_2 small, and *k* is large. The method is more efficient than the ordinary spark on two accounts: firstly, because there is less loss of power in the transmitting circuits, and secondly, because all the radiated energy is of one wave-length, and is therefore all available in the receiver.*

Accurate tuning between primary and secondary is not essential, and becomes less important as the damping of the primary current is increased up to a certain large value by cooling the electrodes or otherwise. With further increase of the damping new phenomena appear, and Galletti † has shown that with unidirectional-current impulses in the primary very marked tuning is possible. There are thus no beat currents, and the degree of coupling has little effect on the character of the secondary current except in so far as closer coupling causes increase in the primary damping owing to a more rapid transference of the energy from the primary, and hence gives greater efficiency; there are, however, in each case, certain values of the coupling which give the best results.

The Energy Relations of Coupled Circuits.—A very considerable amount of theoretical and experimental work has recently been done on coupled circuits by Pedersen, Austin, and others. Pedersen shows, for instance, that in a coupled receiver with uniform A.C. the maximum energy is taken by the secondary when the energy dissipations in primary and secondary are equal. Austin shows, among other results, the reduction in primary current by coupling to a secondary.

---

* Refer also to remarks on the work of Elihu Thomson, Fessenden, and others in the latter sections of Chapter III., and to Fessenden, *Electrical World*, 19th September 1903, and *Electrician*, 15th and 22nd February 1907.

† *Electrician*, 20th January 1911. See also *Barkhausen*, *Schwingungserzeugung*, p. 84.

Study of Current Characteristics.—It will be seen from the above paragraphs how important a part is played by the coupling and damping of the circuits, in determining the type of wave radiated and its suitability for telegraphic purposes. Now that so many stations are in existence, the avoidance of interference has become by far the most pressing problem for the wireless engineer. Hence it has become essential to know the type of current radiated, and to study methods for reducing the probability of its causing trouble in receiving stations where it is not wanted. At the same time it is necessary from the point of view of economy in commercial work to make sure that the energy supplied to the transmitter is used efficiently, and that as much of it as possible is converted into high frequency current of suitable form. The answers to all these questions depend almost wholly on a thorough study of the decrements and interactions of the circuits of the transmitter. Damping in any oscillating circuit indicates also waste of energy, except in so far as it is caused by transmission of power to another circuit by induction or radiation.

Note.—Another measure of coupling has recently come into use, particularly in America. It is called "percentage" coupling, and is defined experimentally as the ratio of the difference of the wave-lengths of the beat waves produced by coupling, divided by the free wave-length of either circuit—this latter being the same for primary and secondary. The numerical value obtained by this method is a rough approximation to that obtained by the more accurate methods given above, and in Chapter XVIII. Its recommendation is obviously its simplicity.

CHAPTER XVI.

THE THEORY OF TRANSMISSION.

IN Chapter I. some suggestions have been made as to the way in which the electrical energy sent out by the transmitter may reach the receiver. Opinions still differ somewhat as to the actual mechanism of the process, as, for instance, in regard to the part played by the earth, and the importance of free as opposed to conducted radiation; and a large number of facts as to variations in the possible distance of transmission on account of intervening hills and atmospheric conditions have yet to be allotted their proper places in the general scheme.

The possible fulfilment of a mathematical prophecy which we shall consider in the next chapter is a unique case in regard to the electrical transmission of energy for telegraphy or other purposes, and presents less mathematical difficulty than the more ordinary systems. It is these latter, however, that we must deal with at present, and in doing so it will be well to commence with a survey of the electrical properties of the system of conductors and dielectrics with which we have to deal.

The Atmosphere.—This is a thin spherical shell composed of a rather complex mixture of gases, bounded internally by the surface of the earth or sea, and externally by what is probably a nearly perfect vacuum. Well-known facts in regard to meteorites and other cosmical phenomena show that the thickness of the shell is not much over 100 miles; it is therefore thin in proportion to its diameter, which is approximately 8,000 miles, and thin also in proportion to the distances of over 2,000 miles which are common in wireless telegraphy. At the earth's surface the air pressure is about 15 lbs. on the square inch, and the density is about .08 lb. per cubic foot; at the outer surface of the shell, say 100 miles above the earth, both pressure and density are zero. The pressure and density at any intermediate point are calculable by the well-known barometric formula.

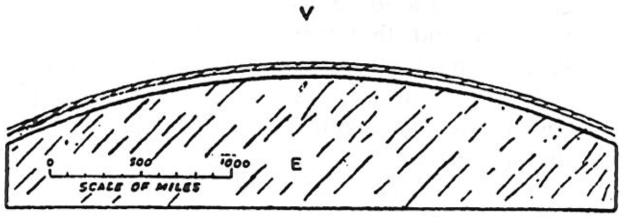


FIG. 152.

A portion of the Earth and Atmosphere, to scale. *E*, the Earth; *V*, Outer Space. The shaded parts are conductors, the strip between them being the dielectric of Wireless Telegraphy.

The electrical properties of air at various pressures are well known. At 15 lbs. on the square inch it is, except for extremely high voltages, a nearly perfect dielectric or non-conductor—that is to say, lines of electric force can travel through it without appreciable loss by dissipation of energy. At a low pressure such as exists at about 35 miles above the earth, it becomes suddenly conductive, and at the pressure which must exist a few miles higher up its conductivity, for high frequency currents without electrodes, is as great as that of a 25 per cent. solution of sulphuric acid, so great, in fact, that a layer of half an inch thick forms a complete screen through which electric waves do not pass.[*] At lower pressures, about 80 miles up, it becomes such a non-conductor as we know it in "hard" X-ray tubes, and, farther up still, as perfect a dielectric as is known. There is a critical value of the pressure, which occurs at about 35 miles, below which height the air is practically a non-conductor, and above which its conductivity rapidly attains that of the best electrolytes. The *non-conducting* shell of air which surrounds the earth is therefore only about 35 miles thick—less than one hundredth part of its radius—and is bounded below by earth, which has a resistance of about 6,600 ohms per c.c., or sea, with 373 ohms per c.c.,[*] and above by a layer having a resistance of not more than 10 ohms per c.c. The upper shell then conducts at least 660 times as well as damp earth, and nearly 40 times as well as the sea.

This intermediate non-conducting shell of air is the dielectric with which we have to deal in wireless telegraphy. Though in general a good insulator, its properties in this respect are by no means constant, its ionisation, and consequently its conductivity, being subject to both regular and irregular changes. The most important of the former is the diurnal variation corresponding to the daily variation of atmospheric electrification. The maxima at the earth's surface occur between 8 and 10 A.M., and between 10 P.M. and 1 A.M., the minima being at 2 P.M. and 4 A.M. It has been found that even air in closed vessels, as well as in the open, is subject to these variations.[†] In both cases the effect is most probably due, directly or indirectly, to streams of electrified particles, ejected by the sun, impinging on the upper atmosphere; the daily variation being caused by the rotation of the earth presenting different parts in turn to the rays.

The maxima and minima just given are those observed near the earth's surface. Higher up, the variation, as far as is known, has only one maximum and one minimum daily, the former about noon and the latter at 5 A.M. The times of maximum conductivity are those at which there is

---

[*] J. J. Thomson, "Recent Researches in Electricity."

---

[*] Brylinski, *Soc. Internat. Elect. Bulletin*, 6, p. 255, June 1906.

[†] A. Wood, *Nature*, 73, p. 583, April 19, 1906.

greatest dissipation of energy in the transmission of electric force through the dielectric. This occurs in the air not in contact with the earth every day about noon. The time of minimum conductivity occurs about 5 A.M., and it is usually in the latter part of the night that wireless signals travel farthest.

It may seem curious that increase of conductivity of the dielectric causes increase of dissipation of energy, and therefore less efficient transmission; the difficulty will be at once removed, however, when it is remembered that in all modes of transmission of electrical energy it is necessary to have good insulation, and that any leakage in the insulator causes waste, and prevents a proportion of the energy reaching the desired point. The discoverer of this difference between day and night was Mr Marconi, who found, while on a voyage to America, that signals which failed entirely during the day at distances of more than 700 miles were easily obtained up to 1,500 miles during the night. The time at which the greatest change occurred was about 7 A.M. at the transmitting station, which, as the experiments were made about the 1st of March, was just after sunrise there. He therefore put forward the theory that the weakening must be due to the action of daylight on the transmitting aerial itself. Professor J. J. Thomson has, however, shown that the waste of energy due to ionisation of the air should be greatest where the electrical energy is most concentrated, *i.e.*, near the transmitting aerial, and that it increases with the wave-length of the transmitted jig.

The phenomenon might therefore be explained as well on this as on Marconi's hypothesis, and the fact that it is only observable in transmission to long distances favours the supposition that the loss does not only take place at the aerial but is to some extent distributed throughout the whole course. (See "Day and Night Variations," below).

Captain Jackson's observations on similar alterations in the possible distance of signalling, due not to day and night but to other changes in atmospheric conditions, are very

interesting. He has found that the maximum signalling distance may be reduced from 65 to 22 miles in apparently fine weather, though as a rule, such changes are the accompaniment of a falling barometer and the approach of stormy conditions.

It was also found that during a scirocco wind, which is damp and laden with dust from the African coast, the distance was very considerably reduced.

In both cases a change in the properties of the atmosphere is evidently the cause of the variation, and apparently the change is one which causes increased conductivity and therefore greater dissipation of energy of the waves which are propagated through the air.

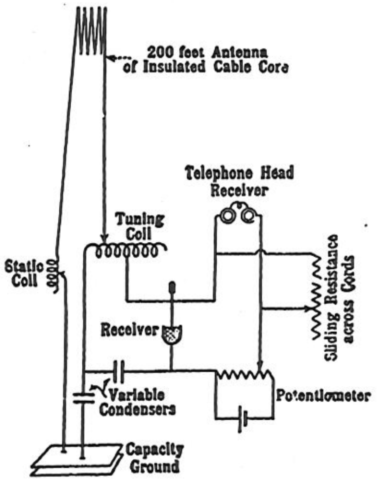


FIG. 153.—CAPTAIN WILDMAN'S METHOD OF TESTING THE INTENSITY OF SIGNALS.

Captain Wildman, of the United States Army, has found that in damp and stormy weather the transmission of signals becomes more difficult. His observations were made across Norton Sound, in Alaska, between stations at Safety and St Michael, the distance being 107 miles. By shunting the receiving telephone (as shown in Fig. 153) the strength of the signals could be reduced to a point at which they were just audible. The conductivity of the shunt required indicates the strength of current in receiving aerial, as it shows how much the current may be cut down without causing signals to become inaudible.

Early in March 1906 Captain Wildman kindly sent me the diagram (Fig. 154) and notes given below. The obvious conclusion which may be drawn from these results is that stormy damp weather reduces the strength of signals. This coincides with Captain Jackson's observations, and as the receivers used in the two cases were entirely different it is safe to locate the cause of the variation outside the instrument room, *i.e.*, either on the aerials, or, more probably, in the atmosphere.

NOTES BY CAPTAIN WILDMAN.—The thin line representing temperatures can be easily traced, the horizontal being marked in the extreme left-hand column, directly underneath the lines 32.

The upper dot and dash line is a record of the hot-wire ammeter at the sending station. It is merely a relative measure, and does not read directly in amperes. A 2-ampere Jones and Phillipps hot-wire ammeter, with a large shunt uncalibrated for highly oscillating currents, was used. In practice, the inductance in the closed oscillating and open radiating circuits are moved until the maximum reading on the hot-wire ammeter is obtained.

The lower dot and dash line represents barometer readings, and its scale is between 29 and 31, marked at the extreme left.

The broken line represents wind velocity in miles per hour, with its scale nearest the margin of the chart.

The thick line represents resistance on coherer obtained by putting non-inductive resistance across the telephone cords.

This gives the relative measure of loudness in the receiver.

The points on the chart marked with a * are practically the only points where discrepancies occur in the parallelism of the wind and resistance curves.

Those on the 25th of November and the 13th of December are easily explained as errors in the reading of the operator, or much noise in the room, making acute hearing an impossibility.

That on 5th January I am unable to explain, unless the day were very, very dry, and the wind velocity made no difference, taken in connection with the fact that the hot-wire ammeter reading was greater than it had been for many days. It is also possible that the operator, by practice, had been able to cut down the sound in the telephone receiver, to a greater extent than when the observations were first commenced. On the whole, the two lines parallel each other so well, that there is no doubt in my mind that there is some connection between the wind velocity and the travelling, or about to travel, electromagnetic wave.

obvious
is that
s. This
l as the
ent it is
e instru-
robably,

resenting
arked in
s 32.
ammeter
does not
hot-wire
currents,
ting and
ng on the

s, and its

nour, with

by putting

er.
cally the
the wind

mber are
uch noise

day were
n in con-
s greater
operator,
telephone
were first
r so well,
onnection
l, electro-

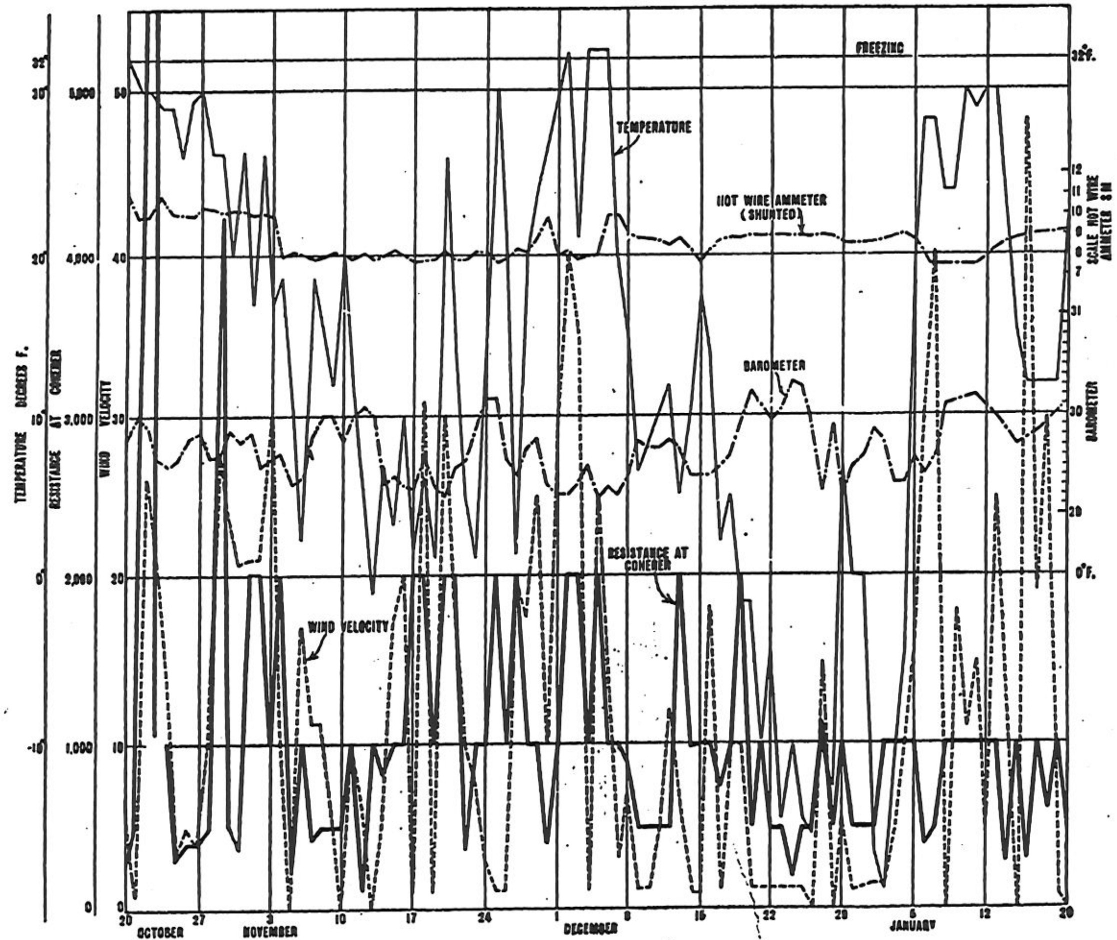


FIG. 154.—DIAGRAM ILLUSTRATING OBSERVATIONS MADE BY CAPTAIN WILDMAN (SEE HIS "NOTES") ACROSS NORTON SOUND, IN ALASKA

To face page 268.]

Great variations in the strength of the received current have also been observed at the transatlantic stations of the Fessenden system. The curve (Fig. 112, p. 189) shows the enormous variations which may occur in the course of a few days, due to causes apparently beyond the control of the operators; *e.g.*, to atmospheric changes.

In Canada an increase of range to six times the normal has been observed immediately after an aurora borealis.

The Earth.—Let us now consider the electrical properties of the other factor concerned in transmission, viz., the earth. This body is, roughly, a sphere of about 4,000 miles radius. Its properties as a single electrical conductor will be considered in the next chapter, in the meantime we shall confine ourselves to the conductivity of its upper layers, since these only are concerned in ordinary wireless telegraphy, because high frequency currents do not penetrate far into a conductor.

M. Brylinski, in an exhaustive paper on the resistance of conductors to variable currents,* discusses thoroughly the resistance of the earth and sea to currents of low and high frequencies, whether uniformly alternating or damped. Assuming the value 6,600 ohms per c.c., based on experiments, for the resistance of damp earth, and unit permeability, M. Brylinski shows that if the frequency of alternation of a current be 10 millions per second, which corresponds roughly to those employed in wireless transmission, practically the whole current will be confined to a layer not more than 15 metres deep. If the current be damped, the depth is decreased, and therefore the effective resistance is increased.

The depth of the useful layer in salt water is about one quarter of that in earth, *i.e.*, about 4 metres; but as the conductivity of salt water is about seventeen times as great as that of soil, the effective resistance is much less.

---

* *Soc. Int. Elect. Bulletin*, 6, pp. 255-300, June 1906.

If the soil contain iron or other magnetic material, the depth of penetration is enormously decreased.

These facts probably account in great part for differences in the possible distance of transmission over hills of various materials which were observed by Captain Jackson in a most interesting series of experiments, which we shall consider later.

Stated in words, M. Brylinski's principal result is as follows:—In spite of the infinite depth of the conductor, the resistance of a strip of finite width has a finite and calculable value which increases with the specific resistance, with the frequency, with the permeability, and with the damping. He has also calculated a similar formula for the inductance of the useful layer.

Thus we see that if a jig of given frequency and damping is conducted along the earth's surface, the resistance of the layer which carries the current is increased if the specific resistance or permeability is increased. Now let us examine Captain Jackson's observations, which are the result of a large number of experiments made between vessels fitted with what is practically his own system of wireless telegraphy. In each case the maximum distance of transmission over sea was known, so that the reduction due to any intervening land could be found by direct experiment. In all cases a certain proportion of the distance, generally much the greater part, was sea, a fact which must be kept in mind in what follows. Experiments such as these, showing actual dissipation of energy *en route*, in addition to the reduction due to the increasing diameter of the wave, assist greatly in making clear the method of propagation of the waves. The chief results may be summarised thus:—

If the possible distance over sea be taken as 100, the distance when sandstone or shale intervened was 72, with hard limestone intervening 58, and with limestone containing iron ores, 32.

Now, recollecting that sandstone has a much higher resistance than sea water, and limestone than sandstone, and that limestone containing iron ores has both high resistance and permeability, we are at once driven to the conclusion, by comparison of these figures with M. Brylinski's formula, that the distance to which wireless transmission is possible is governed to a large extent by the resistivity and permeability of the useful upper layer of the earth or sea. Since, therefore, the nature of the earth's surface determines the distance to which signals can be transmitted, it is clear that whatever be the distribution and shape of the lines of force in the atmosphere, transmission depends directly on the action of the earth as a conductor—at least in an earthed system such as was used by Captain Jackson.

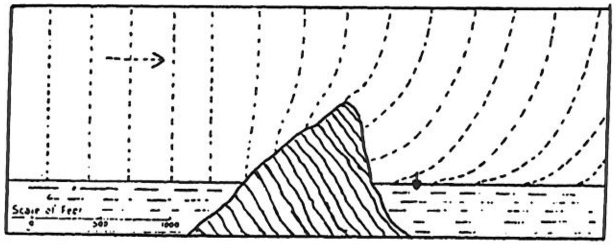


FIG. 155.—DIAGRAM EXPLANATORY OF ONE OF CAPTAIN JACKSON'S EXPERIMENTS ON SCREENING. (Roughly to Scale.)

Having established so much, let us consider the course of the lines of force which accompany the current. In general a line of electric force is at right angles to a conductor where it meets it; in our case, therefore, they are approximately vertical to the surface of the earth or sea. If they are, as we suppose, travelling with their ends continuously attached to the earth, they will be at right angles to the surface whether this surface be level or not. Also if sharp bends occur in the surface, the lines will also be bent at a short distance above the surface.

One of Captain Jackson's observations appears to bear directly on this latter question. It is a case in which signals suddenly failed when the motion of the receiving vessel brought a high promontory of land between her and the transmitter. I have made a sketch, roughly to scale, from Captain Jackson's description of this experiment, showing the position of the ship and the cliff, and I have put in approximately the moving lines of force. It will be seen that the mast and aerial wire on the ship are at such an angle to the lines of force that even if the resistance of the land had not previously reduced the current, no signals could be received. The aerial practically lies parallel to the surface of the earth (the face of the cliff), with the insulated end pointing towards the direction from which the waves come. This position is, as is well known, an extremely disadvantageous one for the reception of signals. That the bending of the lines and not their absence is, in part at least, the cause of this apparent screening, is rendered still more probable by the observation that though no signals could be received close to the land, in one instance, they could be obtained at a greater distance from the transmitter by moving the ship away from the land in a straight line. Our explanation is that the lines have approximately regained their vertical direction.

If, in the first experiment, Captain Jackson had inclined the aerial away from the cliff at a considerable angle he would probably have received signals.

It is also true that these sudden changes of direction of motion cause some dissipation of energy owing to the induction of what are practically eddy currents in the conducting surface, and that any bend in a conductor means an increase of inductance. Recent experiments by Mr de Forest and Mr Marconi, described in Chapter XIV., with horizontal wires laid on the ground or at only a short distance above it, entirely confirm the theory that in these systems of telegraphy the lines of force are attached to the earth, and are guided by it.

Leaving for a time the consideration of the earth currents, and of the field of electric force immediately above the earth's surface, let us see what must occur in the intermediate and upper regions of the atmosphere.

Firstly we must notice that by an application of Lord Kelvin's method of "Electrical Images," which appears to be perfectly legitimate in the circumstances, it has been shown that the form of the lines of force in the case of a vertical aerial conductor with spark-gap at the bottom is the same as would be produced if a second aerial equally, but oppositely charged, and of the same dimensions, were run vertically downwards from the spark-gap, and the earth removed altogether. This statement, of course, only holds if the surface of the earth be a plane perfectly conducting surface, hills and variations in the nature of the surface will make certain modifications and corrections necessary. The lines of force may thus be taken from Hertz's diagrams by drawing a horizontal line through the middle point of the oscillator to represent the earth's surface, and obliterating the part of the diagram below it: their form is shown in Figs. 10-13, page 18. (See also page 279 *et seq.*)

As these hemispherical waves attain larger and larger diameter their wave-length remains constant, hence the width of the strip on which the base of the wave stands is constant. Thus at the earth's surface the only variation is in the circumference of the strip, and as this is inversely proportional to the distance from the transmitter we find that the electric force and the displacement at any point of the surface are inversely proportional to the distance from the transmitter. The energy per unit volume, which is proportional to the product of the force into the displacement, is therefore inversely proportional to the square of the distance.

The maximum is in the immediate neighbourhood of the surface, if the wave be spherical; higher up the energy becomes less and less dense, and is zero in the vertical line above the aerial. The propagation of this type of electrical disturbance has been investigated by Heaviside and by Blondel. Heaviside has also suggested that an upper conducting layer of the atmosphere might prevent the radiation of electrical energy into space, and so modify the spherical form of the waves, rendering them ultimately cylindrical at a considerable distance from the origin.* In a paper communicated to the Institution of Electrical Engineers, in December 1905, the author independently restated this proposition, and adduced some arguments in its favour, including the experimental results of Professor J. J. Thomson mentioned above, and the observations of auroræ recently made by Danish meteorologists, which prove that auroræ are limited to the layer of the atmosphere between six and sixty miles above the earth's surface, and therefore that this layer is conductive; since then a further proof, which will be considered later in the chapter, has been given of the part played by the upper atmosphere, confirming by direct electrical experiment the conclusions deduced in the earlier part of this chapter from physical considerations.

Messrs Duddell and Taylor† found from experiments made between a station at Howth and H.M.T.S. "Monarch" in the Irish Channel, that the received current received varies at distances beyond ten or fifteen miles, in almost exact simple inverse proportion to the distance between the stations. The result admits of no question, the experiments having been carried out most carefully and with wonderfully concordant results. They have been fully confirmed by Lieutenant Tissot.‡ The measurements were made with Mr Duddell's thermo-ammeter and thermo-galvanometer, the former in the transmitting aerial and the latter in the receiver. The greatest distance reached was Holyhead, sixty miles from the station at Howth. The results of these experiments are of so great importance that with the kind permission of the authors I reproduce the diagrams which give the details. There are many interesting points to be noted in connection with them, explanations of some of which we may be able to give from consideration of our deductions from the work of M. Brylinski and Captain Jackson.

---

* "Encyclopædia Britannica," art. Telegraphy, vol. 33, p. 215.

† *Journal of the Institution of Electrical Engineers*, No. 174, vol. 35, July 1905.

‡ *Ibid.* No. 177, vol. 36, April 1906.

Admitting then, as is generally done by those best qualified to judge, that the application of the method of electrical images, described above, to the problem of determining the form of the lines of force during their outward motion, is legitimate, we see that waves must on the earth's surface consist of a series of concentric circles whose centre is the transmitter. The width of the annular strip containing the jig will be approximately constant, and will depend on the number of waves in the jig and on the wave-

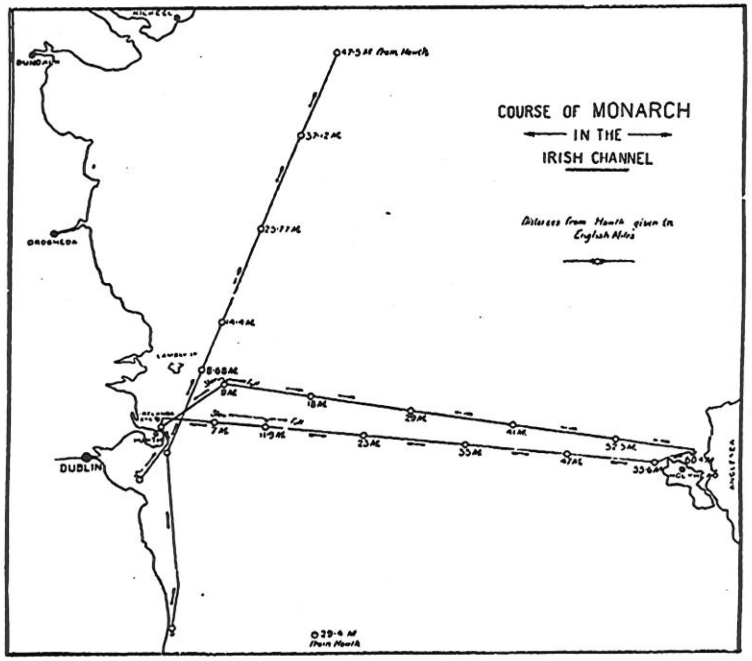


Fig. 156.—Duddell and Taylor's Sketch Chart, Howth to Holyhead.

length. In the transmission of a jig to distances greater than (wave-length) × (number of waves in the jig), the last

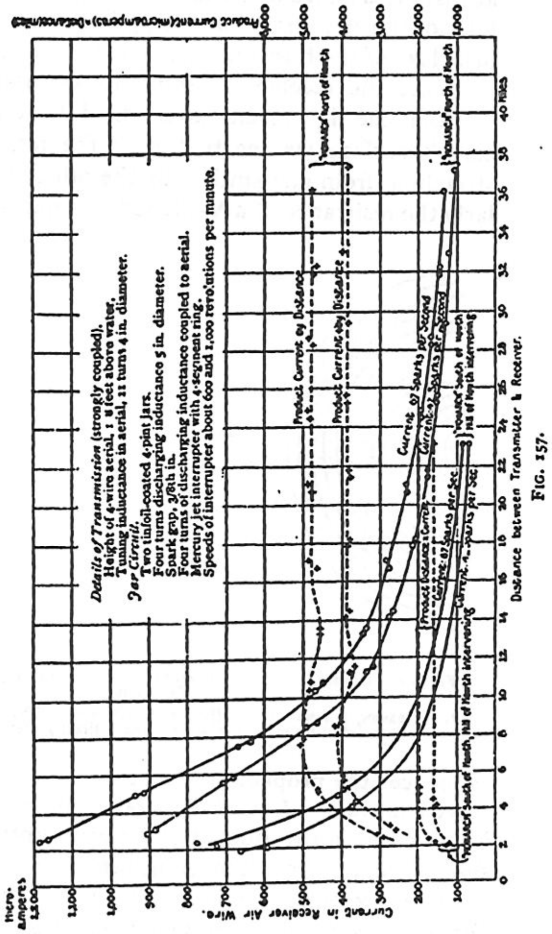


FIG. 157.

wave will have left the transmitter before the first has arrived at the receiver. Hence in this case the receiver has

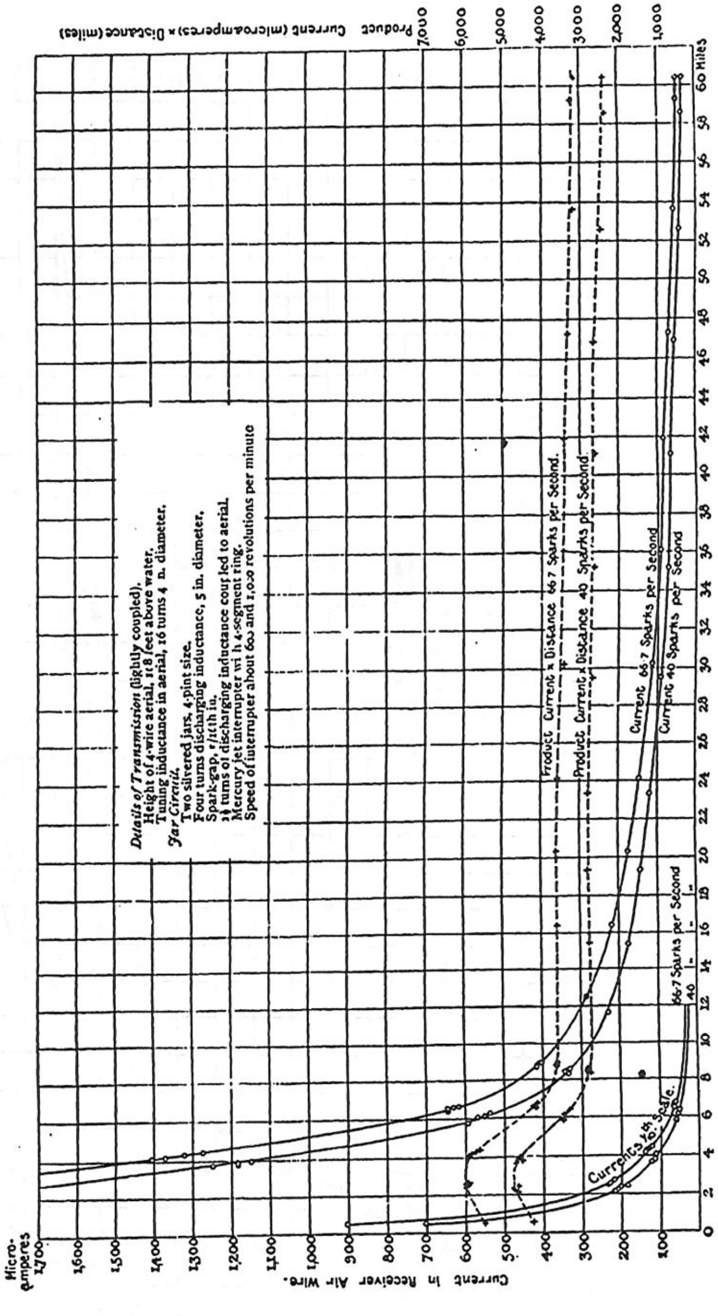


FIG. 158.—"Monarch" crossing from Howth to Holyhead.

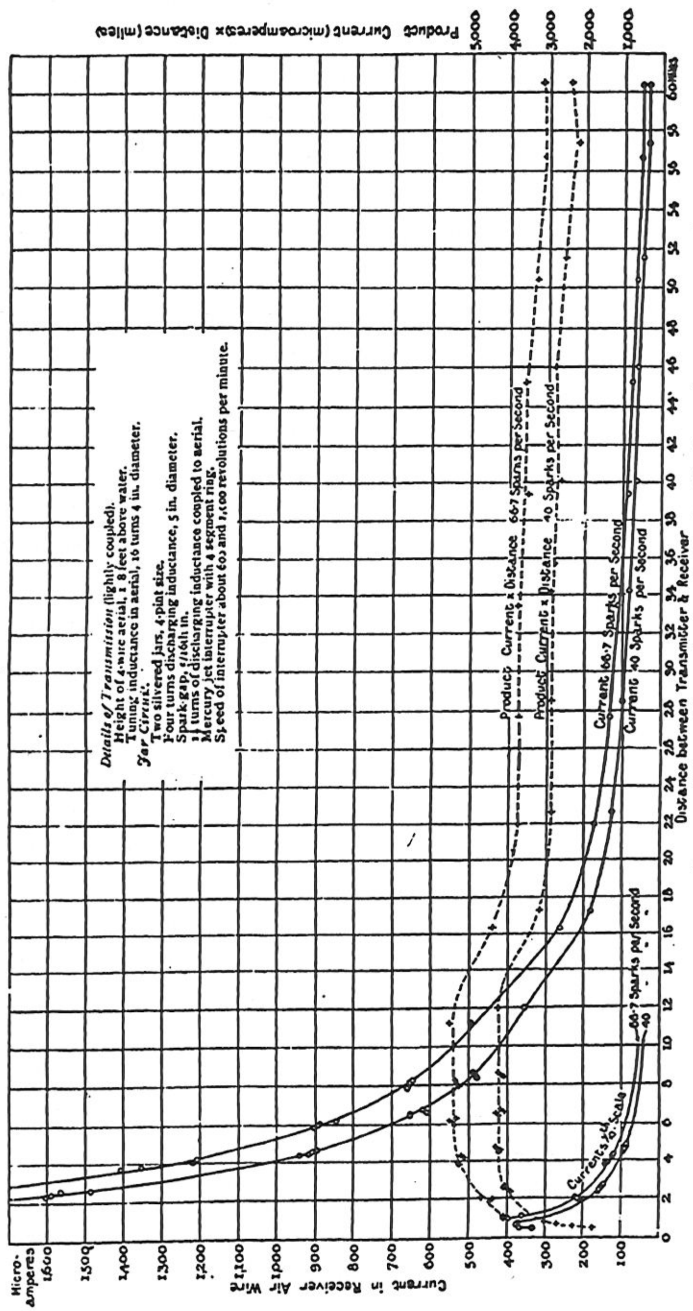


FIG. 159.—"Monarch" returning from Holyhead to Howth.

no influence on the transmitter. This is generally the case at distances above a few miles. Fig. 160 shows roughly the form of the wave fronts of the jig in two positions—(1) when just clear of the transmitter, and (2) when it has commenced to affect the receiver. From this diagram, and from the fact that the jig current is confined to a thin layer of the earth's surface, we see that it is the resistance of a strip stretching from one station to the other, and more particularly the resistance of a V-shaped slab near each station that

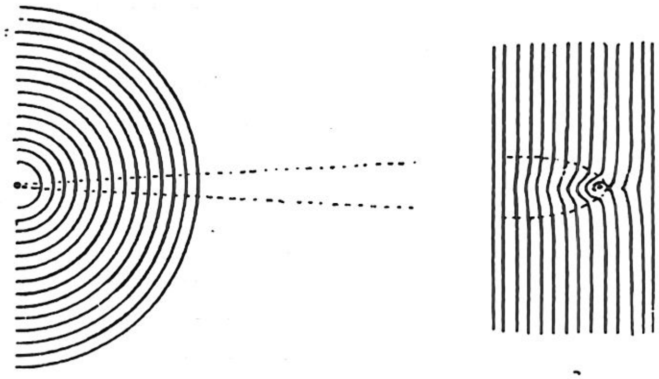


FIG. 160.—DIAGRAM SHOWING PLAN OF PROPAGATION OF JIGS ALONG EARTH'S SURFACE.

A, Jig leaving Transmitter; *B*, Jig affecting Receiver. The dotted lines enclose the "useful strip" of earth whose resistance directly effects transmission.

influences the propagation of the jig, and therefore the received current. Let us first take the case of two stations both of which are situated on an interrupted plain or on the sea. The jig from the transmitter travels outwards unmodified except by its increasing circumference and by the slight losses due to frictional dissipation of energy caused by the resistance of the earth and the imperfect insulation of the atmosphere. Neglecting the frictional losses for the present, we see that theory, confirmed by Duddell and Taylor's experiments, gives a variation in the electric force, and therefore in the received current, which is inversely proportional to the distance from the transmitter. We shall call this the law of divergence, as it shows the loss of energy due to purely geometrical considerations. It may be expressed symbolically as

$$c = \frac{K}{d}$$

where c is the current in the receiving aerial, d the distance of transmission, and K a constant.

If we take the curvature of the earth into account, and proceed to trace the variation of the wave front at greater distances than those of Duddell's experiments, which only extended to sixty miles, we find from simple mathematical or rather geographical, considerations that the radius of the circle in which the wave front cuts the globe is directly proportional to the sine of the angle at the earth's centre subtended by the arc of the surface between the transmitter and the wave front. This agrees with Duddell's law, because for small distances $\sin\theta$ is nearly equal to θ. For greater distances, however, the divergence becomes less and less, and at distances beyond 6,000 miles, *i.e.*, beyond $\theta = \frac{\pi}{2}$, the waves converge, and the current should increase with distance. This is true on any theory whatever, as the wave front is becoming a smaller and smaller ring, continually converging from all sides towards the antipodes of the transmitting station.

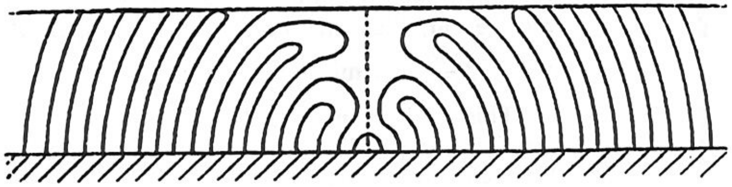


FIG. 161.

The equation for the received current is thus of the form :—

$$c = \frac{C_1}{\sin\theta}; \quad - \quad - \quad - \quad - \quad \text{(A)}$$

where c is the received current, θ the angle defined above, and C a constant.

Fig. 161 gives a rough representation of the lines of electric force as they spread from the transmitter outwards.

The above law of variation of the received current with distance is obviously not complete. We have so far supposed that the lowest layer of the atmosphere is a perfect dielectric, that the earth is a perfect conductor, and that the upper atmosphere does not affect transmission, *i.e.*, that the decrease of current is simply due to increase in area of the wave front.

We must now take account of frictional losses, in order to complete the law as far as possible; though with the data at present available only a rough approximation can be attempted. It will be possible to amplify the equation when further measurements have been made, and to determine more exactly the functions and constants involved.

The first indication of a true frictional dissipation of energy in transmission was found in Marconi's discovery that messages could be received at much greater distances during the night than by day. There cannot be much difference between the divergence variations by night and day, as the earth does not change its shape; this phenomenon has therefore to be explained by some difference in the electrical properties of the transmitting media. Now the conductivity of the earth cannot be seriously altered by the sun's rays; the atmosphere, however, may be much affected. Cosmical science has made many striking advances lately, and it is now practically certain that streams of electrified particles, resembling the cathode rays, are ejected from the sun with a very high velocity. These penetrate the earth's atmosphere on the day side, electrifying it, and at the same time ionising it, thus rendering it more conductive. During the night equilibrium becomes slowly restored, and towards five o'clock in the morning a very marked minimum of atmospheric electrification has long been known to exist. The time at which signals go farthest thus coincides with a minimum conductivity of the lower layers of the atmosphere, while greater conductivity of the lower layers during the daytime coincides with greater difficulty in transmission.*

Now an electric wave must have either an all-dielectric medium or a dielectric bounded by conductors; it cannot penetrate far through a conductor. Thus if all the atmosphere were conductive the wave would travel only a very short distance before being dissipated by resistance, and transmission to a great distance would be impossible. The conditions would be similar to an attempt to transmit current along a concentric cable with bad insulation between the conductors. The good insulation is just as essential as the conductors. We may take it, then, that during the night the lowest ten miles of the atmosphere is a good dielectric, while during the day it becomes slightly conductive.

To obtain a rough estimate of the amount of this dissipation, we may take Mr Marconi's statement, that 500 miles during the day is roughly equivalent to 1,000 by night.† The variation is not so noticeable at short distances, being in this case so very much less important than the divergence, though it is distinctly traceable in Duddell and Taylor's results.

Let us assume that the law of divergence is that given above—Equation (A)—*i.e.*, that the undissipated current would vary inversely as the sine of the angle between the places, or approximately, for the distances under consideration, inversely as the distance along the earth's surface.

---

* This change is however too small to account for the whole phenomena observed; see "Theory of Day and Night Ranges," below.

† Fessenden (1908) has shown that absorption by day reaches a maximum at 120,000 per second as the frequency is reduced, and drops to a minimum value at 80,000.

We then have the law of divergence $c \times d =$ constant, where c is current received, and d is distance between the stations.

Now assume as a first approximation that there is no dissipation at night; then the current lost, by divergence only, between 500 and 1,000 miles at night is all spent by dissipation during the day before 500 miles is reached. Again, the divergence alone between 500 and 1,000 miles would reduce the current to one-half, since 1,000 is twice 500. Therefore the current at 500 miles during the night is twice the current which will just work the receiver. The current lost by dissipation during the day throughout 500 miles is therefore equal to that which will just work the receiver. We have thus obtained an approximate value of the dissipation from Mr Marconi's experiments. If we call the minimum working receiver current of Mr Marconi's receiver M, then the current lost through dissipation is roughly $\frac{M}{500}$ per mile.

This dissipation is no doubt a function of the distance, the form of which I hope to be able to determine later. It is also, of course, a function of the state of the atmosphere, as regards electrification, and varies from a minimum in the very early morning to a maximum in the evening. In the meantime we may take $\frac{M}{500}$ as a rough approximation to its average mid-day value, under the circumstances considered.

The approximate equation $c = \frac{C}{\sin\theta}$ for propagation of signals then becomes—

$$c = \frac{C}{\sin\theta} - \frac{M}{500}d, \qquad \text{(B)}$$

where c = received current,
C = a constant,
M = minimum current which will actuate receiver,
d = miles distance,
and θ = angle subtended at centre of earth by arc d.

Now since $\frac{d}{3500}=\theta$, approximately, since the earth's radius is 3,500 nautical miles, $\therefore d=3{,}500\,\theta$.

To determine C from (A) we notice that $c=C$, if $\sin\theta=1$, *i.e.*, if $\theta=\frac{\pi}{2}$. C is thus the value of c at 5,400 nautical miles, or an earth quadrant from the transmitter during the night, *i.e.*, when *no* dissipation. We may state it as $C=kM$ if we like to take M as a unit, *i.e.*, the undissipated current at 5,400 nauts. is k times that necessary to work the receiver.

The equation then becomes—

$$c=M\left(\frac{k}{\sin\theta}-7\theta\right) \quad - \quad - \quad - \quad (C)$$

To find the limit of distance with any given power we must have $c=M$, *i.e.*, the current at the receiver is just the smallest possible working current.

The equation (C) then becomes—

$$1=\frac{k}{\sin\theta}-7\theta, \quad - \quad - \quad - \quad (D)$$

or—

$$k-\sin\theta\,(7\theta+1)=0 \quad - \quad - \quad - \quad (D^1)$$

The number seven in this equation is only a rough approximation, suitable to the case under consideration. It should properly be replaced by some function of θ.

Let us now consider Duddell and Taylor's results for shorter distances in the light of this explanation.

Remarking on the slight decrease in the product $c\times d$ at long distances, they suggest reflection from the Hill of Howth as a cause, mentioning that another possible, but apparently less probable, explanation is that the cross-channel runs were made in damp, misty daylight, while the up-and-down channel course was made in the night and early morning with a clear frosty atmosphere. To me this latter suggestion is far more probable than the first. We know that such a difference exists from Marconi's results. It is worth while to attempt to derive it from Messrs Duddell and Taylor's measurements. We may take from their curves the following data, comparing the day and the night experiments.

(1.) *Night.*

"MONARCH" COMING SOUTH TOWARDS HOWTH.

Distance off Howth	18	...	36	Miles.
$c\times d$	3,850	...	3,820	Micro-amperes × Miles.

Thus at 18 miles the current was 214 mA., and at 36 miles 106.1 mA.

Now, by divergence alone the current would at 36 miles have been one-half that at 18 miles, *i.e.*, 107 mA. The dissipation loss is thus 0.9 mA. in 18 miles, or roughly 0.05 mA. per mile on 214 mA.

(2.) *Day.*

In a similar way we may obtain by averaging curves, representing the same quantities on the voyage to Holyhead and back during the day, the value 7.2 mA. lost between 30 and 60 miles off Howth. This amounts roughly to 0.24 mA. per mile on a maximum current of 120 mA. Reducing the result given in (1) to suit this maximum current, we see that the dissipation by night is to that by day in the ratio of about .025 to .24, *i.e.*, the dissipation during the day is approximately ten times as much as at night.

Messrs Duddell and Taylor attempted to measure the day and night variation between Howth and Kingstown, but did not find as much as 1 per cent. difference. This was natural, as these points are only about six miles apart, hence the total dissipation was very small in both cases. The difference of the values for night and day which I have deduced above would barely amount to 1 per cent. of the total in five miles.

Comparing the value of the dissipation determined from Marconi's experiments with that obtained from Duddell and Taylor's, we find that they are of the same order of magnitude. Nearer than this we cannot at present go, since the minimum working current of Marconi's long-distance receiver is not known.

Effects of Unsymmetrical Distribution of Resistance in the Neighbourhood of the Receiving Station.—Messrs Duddell and Taylor attribute the unexpectedly large currents indicated by the humps in the curves in Figs. 158 and 159, to effects of reflection from the mainland of Howth Head or the islands. When we consider, however, how comparatively slight is the slope of even a " precipitous " headland we see that waves travelling in straight lines would, on striking the slope, be shot up skywards and could by no means reach the receiving station on the earth. Captain Jackson's suggestion made in the discussion on the paper, that the humps might be due to the interference of the two jigs of different wave-length sent out simultaneously by every transmitter, is rendered improbable as an explanation in the present case by the fact that the distance over which the hump stretches is so different in the two voyages of the " Monarch."

I would suggest that the following explanation is free from either objection, and explains the facts more simply.

The Howth receiving station was situated on land near the sea (see sketch map), at a place where the coast line runs approximately east and west. There was therefore land on the east and south sides of the station. Fig. 162 shows how this configuration of the land and sea would affect, by the difference of resistance, the current transmitted. The upper shaded elliptical surface shows the part of the useful strip of the earth's surface near the receiver at the end of the voyage from Holyhead. In this case it is almost entirely sea. The same is true at the commencement of the outward voyage towards Ireland's Eye.

The other shaded portion of the diagram shows that at seven miles out the strip now includes, near the receiver, a large piece of land of high resistance. There is not much further variation in the land included, as the voyage is continued; there is also but little variation in electrical conditions as shown by the curve of Fig. 158.

On the return voyage a more northerly course was taken, and Howth was "opened up" at a much greater distance; thus the amount of land included in the course of the current near the receiver was the same at twenty miles off Howth on the return journey as it had been at seven miles out on the outward trip. The inclusion of a greater length of sea in the useful strip makes but little difference in the total resistance, since the resistance of sea water is

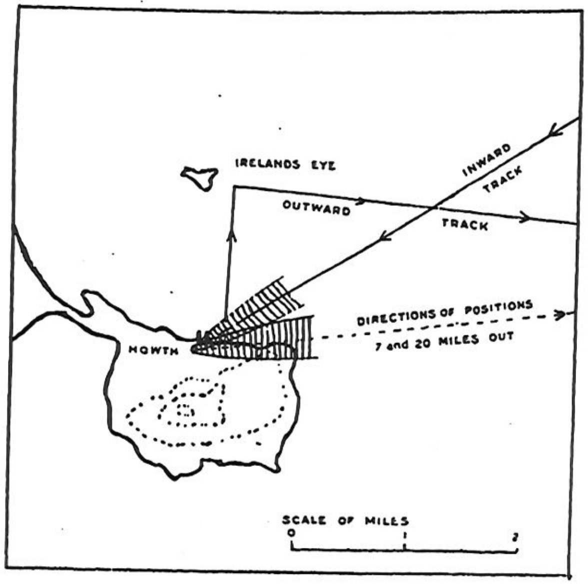


FIG. 162.—DISTRIBUTION OF RESISTANCE NEAR RECEIVER. USEFUL PORTIONS OF WAVE TRAINS ARRIVING AT HOWTH FROM VARIOUS DIRECTIONS.

so low; the resistances in the two cases are therefore practically equal.

Now the products (received current) (distance), whose values indicate the losses of energy from causes other than simple geometrical divergence, are, when the "Monarch" was at the positions just mentioned, exactly equal; the "other cause" is therefore almost certainly the *resistance* of the useful strip. The coincidence seems too clear to be the result of chance, and a minute study of the curves and map at smaller and greater distances of transmission, gives nothing but confirmation of the view that under similar atmospheric and instrumental conditions, the resistance of the useful strip is the most important factor, next to geometrical divergence itself, in determining the current received. A comparison, for instance, of the values of the product $c \times d$ for positions north and south of Howth, with that for the intermediate case just cited shows a similar relation. Thus, north of Howth, where the useful strip near the receiver is all sea, $c \times d = 4{,}800$; east of Howth, where nearly half the strip is land, $c \times d = 3{,}600$; and south of Howth, with useful strip all land, $c \times d = 2{,}000$. These numbers indicate an almost exact proportionality between the received current and the conductance of the useful strip near the receiver. Many facts well known to wireless telegraphists, as, for instance, that it is better to place a station on a flat shore near the sea than on a hill farther inland, afford independent evidence of the correctness of this theory.

The above sections of this chapter were written in 1906, and as they formed the first reasoned explanation of the phenomena observed in actual transmission over land and sea by day and night I have let them stand almost as originally written, in spite of obvious imperfections. Since that date much theoretical and experimental work has been done, the chief results of which we shall now consider.

Zenneck's Mathematical Theory.—The above theory, written in 1906, has been amply confirmed in its general

aspect by the recent work of Zenneck (see Chapter XIV.) and others. Zenneck has also shown the extreme importance of the dielectric constant of the earth or sea; his results indicating that this may be of even greater moment than resistance, as regards transmission. He has shown that a plane wave may be reduced to one-third of its value by traversing a few kilometres of dry soil, while over sea a

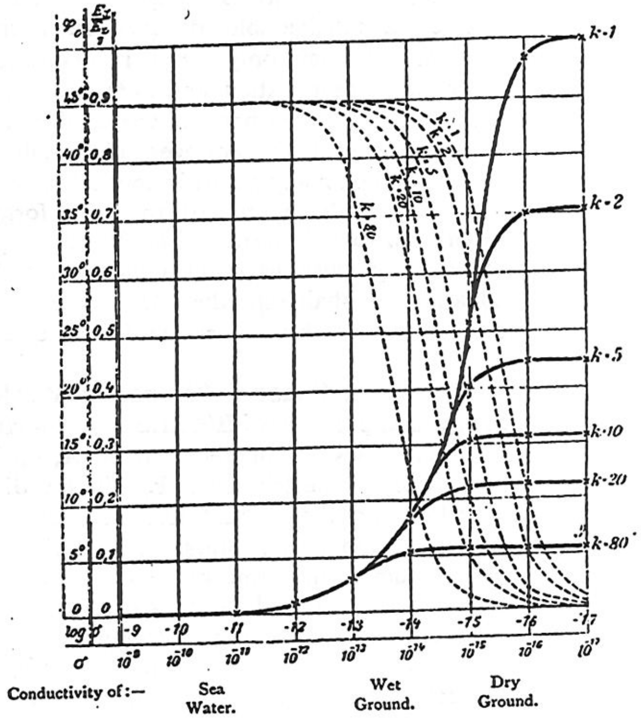


FIG. 163.—RELATIONS BETWEEN HORIZONTAL AND VERTICAL COMPONENTS OF ELECTRIC FORCE OF PLANE WAVE IN AIR, TRAVELLING OVER PLANE SURFACE HAVING CONDUCTIVITY σ AND DIELECTRIC CONSTANT k. (ZENNECK.)

The dotted lines show phase angle, and the full lines the numerical ratio between the Horizontal and Vertical Components.

similar reduction might not take place until 10,000 km. had been reached.

Zenneck's mathematical theory applies to the propagation of plane electro-magnetic waves over the earth's surface. It is, therefore, only directly applicable to the waves radiated from a wireless telegraph transmitter when they are at a considerable distance from the transmitting station, and then only for a moderate distance in the direction of propagation, and to the portion of them in the immediate neighbourhood of the earth's surface. In spite of these limitations, however, his results give valuable information on many points in connection with transmission, and particularly in regard to wave form and rate of absorption by different soils. Without going into the methods by which he obtains them from the Maxwellian equations, I shall reproduce the more important of the diagrams in which they are graphically embodied.

Ratio and Phase Difference of Vertical and Horizontal Components of Electric Force.—His first diagram, Fig. 163, shows the difference in phase, ϕ_0, in air, between the horizontal electric force, E_{ox}, in the direction of propagation, and the vertical force E_{oz}, and also gives the numerical ratio of the forces. The suffix *o* indicates that the medium is the atmosphere, and *x* and *z* indicate the horizontal forward, and the vertical co-ordinates respectively. The curves are drawn for a wave-length of 600 m., *i.e.*, a frequency of 5×10^6. The rule for obtaining from them the corresponding results for other wave-lengths is as follows:—In order to obtain the values for a frequency $a.5.10^5$/sec. and a conductivity σ, look in the diagram (Fig. 163) for the points corresponding to a conductivity σ/a. Higher frequency thus acts like lower conductivity.

The conditions inside the conductor may also be obtained from Fig. 163 for the phase angle in the conductor, $\phi = 90° - \phi_0$, and $E_x/E_z = 1/(E_{ox}/E_{oz})$.

Vector Wave Diagrams.—A more easily understood graphical representation of the differences between the wave forms over surfaces of different conductivity and dielectric constant may be obtained from the curves in the following manner:—

Suppose the electric force at any moment at a point to be represented by a vector, *i.e.*, by a line representing both its magnitude and direction. Throughout a complete cycle the outer end of this line will describe an ellipse, which will have the properties (see Fig. 164) that $OB/OA = E_x/E_z$ and that $OA_1/OA = OB_1/OB = \sin\phi$. Since we have two different sets of conditions in the air and conductor on either side of a point on its surface, only half ellipses are drawn in Figs. 165 to 182. Fig. 165 gives the

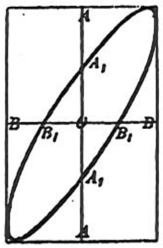


FIG. 164.

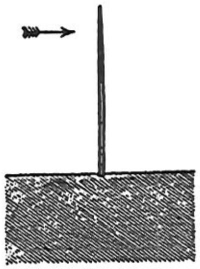


FIG. 165.

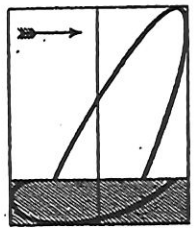


FIG. 166.

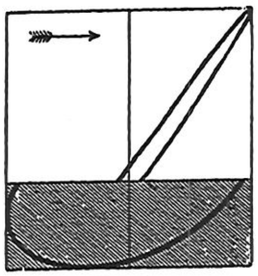


FIG. 167.

vector diagram for a water surface, Fig. 166 for wet ground, and Fig. 167 for very dry ground.

Absorption in Travelling over Various Soils.—Fig. 168 shows the rate of absorption of a plane wave as it travels forward, through an unlimited perfect non-conductor, over a plane conductor, or rather the distance, in kilometres, in travelling over which it would be reduced to 36.7 per cent. ($1/e$) of its value at the commencement of the distance. The ordinates are proportional to the common logarithms of D, the distance, and the abscissæ are the conductivities of the conductor in C.G.S. units ($\sigma = 10^{-9}$ corresponds to a resistance of 1 ohm per c.c.).

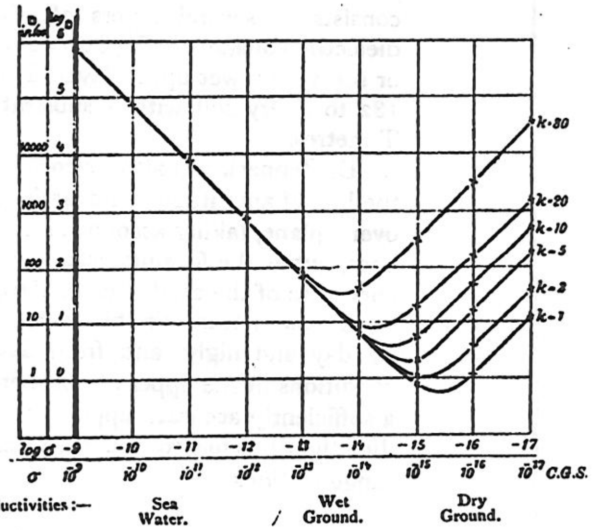


FIG. 168.—DISTANCE, D, IN TRAVELLING OVER WHICH THE AMPLITUDE OF A 600 m. PLANE WAVE IS REDUCED TO 36.7 PER CENT. OF ITS ORIGINAL VALUE, FOR VARIOUS VALUES OF CONDUCTIVITY AND DIELECTRIC CONSTANT OF THE PLANE CONDUCTOR.

For sea water, $\sigma = 10^{-11}$, $k = 80$, $D = 10{,}000$ km. For wet ground, $\sigma = 10^{-13}$, $k = 10$, $D = 80$ km. For dry ground, $\sigma = 10^{-16}$, $k = 4$, $D = 3$ km.

For comparatively short distances, at some distance from the transmitter, where divergence, atmospheric absorption, and the earth's curvature are negligible, this diagram should give good approximations to actual telegraphy. In any case it gives *comparative* values for the absorption by different soils which are directly applicable to practical cases.

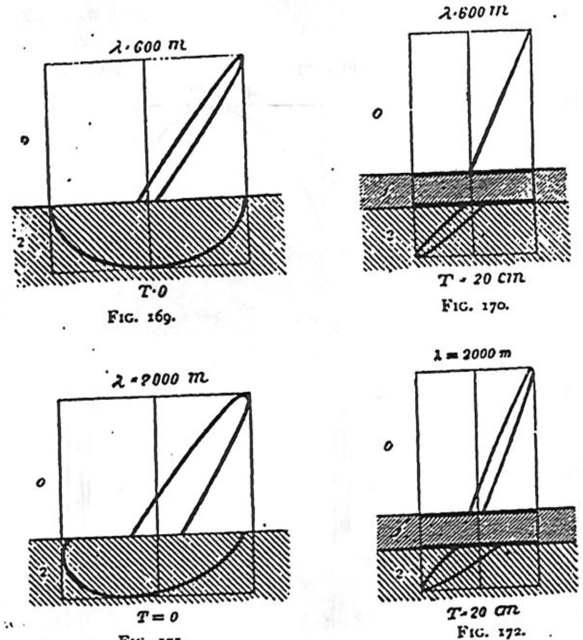


FIG. 169.

FIG. 170.

FIG. 171.

FIG. 172.

FIGS. 169-172.—SHOWING VECTOR WAVE DIAGRAMS FOR DRY SOIL, AND SAM WITH WET UPPER LAYER OF THICKNESS 20 cm.

The advantage in the case of shorter waves is obvious. λ is wave-length. The constants are :—For air, $k = 1$, $\sigma = 0$; for wet soil, $k = 15$, $\sigma = 10^{-13}$; for dry soil, $k = 2$, $\sigma = 10^{-16}$.

To obtain the corresponding results for other wave-lengths, *i.e.*, the distance D at which the amplitude is reduced to 36.7 per cent., let $a\ 5.10^5$ be the new frequency, σ the conductivity, and k the dielectric constant. In the

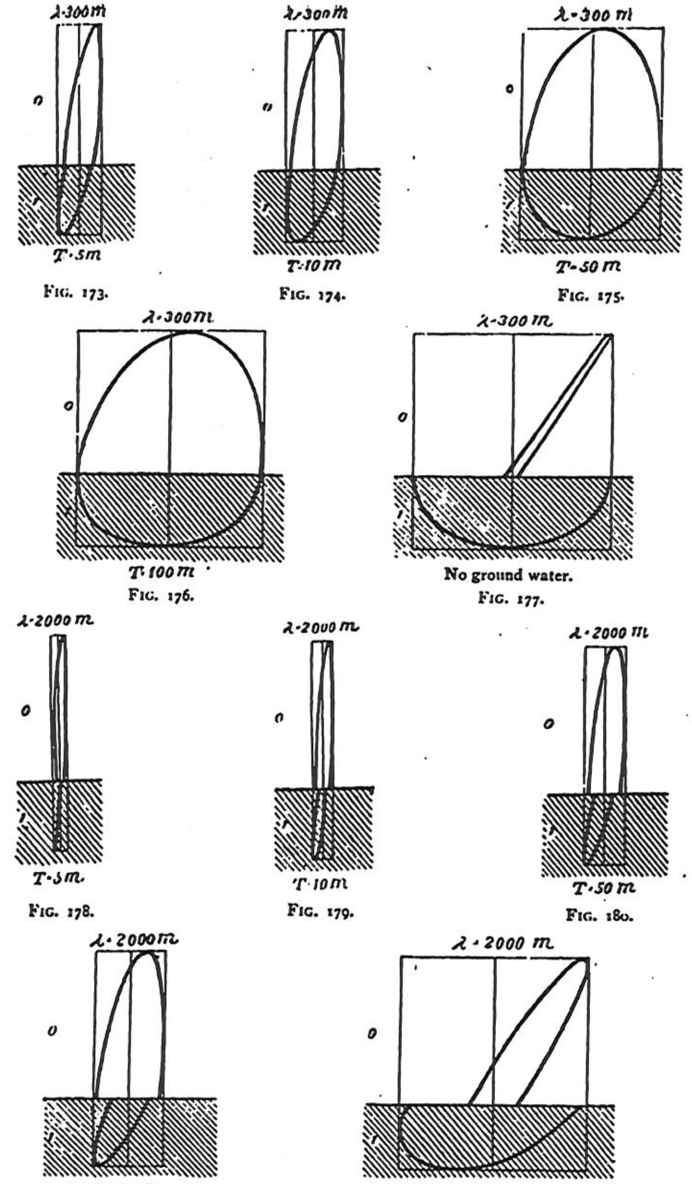


FIG. 173. FIG. 174. FIG. 175.

FIG. 176.

No ground water.
FIG. 177.

FIG. 178. FIG. 179. FIG. 180.

FIG. 181.

No ground water.
FIG. 182.

FIGS. 173-182.—SHOWING VECTOR WAVE DIAGRAMS FOR PROPAGATION OVER DRY SOIL WITH SUBSTRATUM OF WATER AT DEPTH T METRES. (HACK.)

Transmission with long waves is favoured by ground water, though the existence of the latter may affect short waves unfavourably if at depth comparable with wave-length.

diagram find D for *k* and σ/a, and divide the value found by *a*.

Influence of Layers of Different Conductivities.—Dr Zenneck's work has been continued and amplified by F. Hack,* who has calculated the wave diagrams for the practical cases in which the earth is not homogeneous but consists of several layers of different conductivity and dielectric constant. Figs. 169-172 correspond to dry rock or soil with a wet upper layer T cm. thick, and Figs. 173-182 to a dry soil with a substratum of water at a depth T metres.

Dr Zenneck has also given a set of curves representing the loss of amplitude in transmission radially from a station over a plane, taking account of both dissipation and divergence, but as the formula used does not take account of the curvature of the earth (see p. 280), nor of the extraordinary variations in transmissibility of waves of different lengths by day and night, and from day to day, caused by the conditions in the upper atmosphere, the results do not form a sufficiently accurate approximation to actual facts to be directly of value to the engineer in the design of long range stations.

Recent Researches on Transmission.—Since the resistance of the earth's surface layers has so very large an influence on the energy transmitted, it is clear that we are not dealing with free radiation at all, but with electric waves along a conductor as in wire telephony. It is really remarkable that some academic persons still appear to have the quite erroneous idea that practical radio-telegraphy is carried out by free Hertzian waves, apparently for the reason that in the limiting case of transmission over a perfectly conducting plane surface, the mathematical theories are concurrent. This case is in reality approximated to only in the transmission of long waves over sea water, and its mathematical theory has only an indirect bearing on transmission over land or fresh water.

---

* *Ann. d. Physik*, 27, p. 43, 1908.

The latest contributions to the subject are two mathematical papers by Sommerfeld which are excellent as far as they go, but do not touch the extraordinary variations in the strength of signals which occur from time to time. These time variations are a most important but uncertain factor in the determination of the power necessary at any given pair of stations.

Sommerfeld* commences by giving a definition of what he calls the "numerical distance." This is not a real distance but is a numeric, based on the conditions of the media concerned in transmission, such that if equal amounts of power are transmitted between equal pairs of stations their "numerical distances" apart are equal. The power transmitted from one station to another is thus an inverse function of the "numerical distance" between them.

For mathematical purposes Sommerfeld distinguishes between space waves and surface waves, although he points out that physically these are merely different aspects of the same phenomenon. Except in the case of a highly conductive surface such as sea water the space waves die out at very short distances leaving only surface waves.

The mathematical factor representing the space waves shows a variation of energy inversely as the square of the distance, but for surface waves the variation is simply inversely as the distance. In his first paper, taking account of phase difference only he finds that the space waves would be practically negligible in comparison with the surface waves at all usual distances between stations, even over sea. In the second paper he takes amplitude as the criterion and finds that, except in the case of wave-lengths

---

* *Ann. d. Physik*, 23, p. 846, 1910; and *Jahrbuch der drahtlosen Telegraphie*, Bd. 5, Hft. 2, 1910.

of at least 2,000 metres over sea, space waves are practically negligible at the ordinary distances between stations. Over fresh water, for instance, the surface waves become a considerable proportion of the whole disturbance at so short a distance as 4 km. for waves of under 2,000 metres. Surface waves must, therefore, be the prevailing type in all ordinary transmission. Over land the change from space to surface waves takes place at proportionately smaller distances from the sending station.

Sommerfeld's "numerical distance" is calculated from the following data: (1) actual distance, (2) the dielectric constants and conductivities of the earth and air. No consideration is taken of the conductive upper layer of the atmosphere, hence the serious imperfection of the results for practical purposes.

At Sommerfeld's suggestion Epstein has calculated the actual wave forms, at 30 wave-lengths from the transmitter for waves of 200-metre lengths travelling over a surface having the conductivity of fresh water. The most important points shown by these diagrams* are that the lines of electric force cut the ground at angles which vary as the wave passes any given point, and that there are closed loops or "kernels" which in the case of an imperfect conductor, such as is dealt with, are entirely above the earth's surface.

When the nature and function of the upper atmosphere are more clearly understood it will be a comparatively simple matter to extend the work of Zenneck and Sommerfeld so as to include the whole conditions of transmission, and thus to obtain a clear mathematical picture of what actually occurs in the passage of a train of electrical waves from one station to another. I have attempted to give a reasonable explanation of the phenomena in the section of this chapter headed "A Theory of Day and Night Ranges" below.

---

* *Jahrbuch der drahtlosen Telegraphie*, Bd. 4, Hft. 2, 1910.

Austin's Measurements of Long-Distance Transmission Over Sea.—In 1910 Dr L. W. Austin,* of the United States Naval Wireless Department at Washington, carried out a most interesting series of experiments on transmission between a coast station and ships at various distances up to 1,000 nautical miles. The land station used was that at Brant Rock, Massachusetts, at which the antenna is a steel tower about 420 ft. high, the supply power being from 50 to 60 KW. The ships' stations were on board the U.S. cruisers "Birmingham" and "Salem," and on various torpedo boats.

The currents in the transmitting aerial and in the receiving aerial were simultaneously measured in each experiment. The former by a hot-wire ammeter, and the latter at the shore station by a thermo-junction or perikon detector connected to a sensitive galvanometer, and at sea by the shunted telephone method (see p. 349).

As a result of a very large number of observations with a great variety of sending currents, distances and wave-lengths, Austin comes to the conclusion that during daylight the relation between the currents in the transmitting and receiving antenna is very approximately represented by the equation

$$I_R = 4.25\, I_S \frac{h_1 h_2}{\lambda d} \epsilon^{-\frac{\alpha d}{\sqrt{\lambda}}},$$

where I_R and I_S are receiving and sending antenna currents in amperes, the current I_R being through a total resistance of 25 ohms; h_1 h_2 are heights of the antennas; λ the wave-length; d the distance; and α the dissipation constant, which in these experiments averages 0.0015. The wave-lengths, distance, and heights are all in kilometres.

With a total resistance of 25 ohms in the receiving circuit, 40 micro-amperes give good signals, and with 10 micro-amperes they are still audible; the former value may be taken as giving the limit of good working.

---

* *Bulletin of the Bureau of Standards*, Vol. 7, No. 3, Washington, 1911.

It must be noted that the following limitations apply to Dr Austin's experiments and results: (1) Transmission was almost wholly over sea, and measurements were not taken at distances much exceeding 1,000 nautical miles; (2) the currents were damped and intermittent as is usual in spark stations; (3) the ship antennas were of the usual T type, while the Brant Rock antenna was a vertical tower with a small umbrella at the top; (4) the sending currents varied from 7 to 30 amperes, the antenna heights from 37 to 130 ft., the wave-lengths from 300 to 3,750 metres, and the distances up to 1,000 nautical miles. In some similar experiments carried out in 1912 between the Arlington, Va., station of the United States Navy and various ship and land stations, Austin found that up to 530 miles no difference was observable between arc and spark transmission. At greater distances, however, the arc gave the stronger signals. With an arc current in the antenna of about 50 amps., better signals were received at distances over 1,400 miles than with a spark current of 110 amps., *i.e.*, of apparently four times the power. The superiority of uniform waves for long distance transmission appears, therefore, to be definitely established.

A number of interesting observations on abnormal ranges at night are also given to which I shall allude later on.

Theory of the Simultaneous Measurement of Sending and Receiving Currents.—In the *Jahrbuch der drahtlosen Telegraphie*, Vol. 5, No. 3, 1912, Barkhausen discusses the theory of simultaneous measurements of sending and receiving currents such as form the basis of Austin's work. Assuming transmission is entirely over sea, and the whole atmosphere non-conductive, the electric field on the earth's surface at a distance r from the transmitter is

$$E = 120\pi \frac{h'_1 J_1}{\lambda r} \quad - \quad - \quad - \quad - \quad (1)$$

If J_1 is the current at the current-loop in the antenna in amperes, h'_1 the effective height of the antenna, λ the wave-length, and r the distance, all in metres, then E is in volts per metre. The effective height of the antenna is given by the equation

$$h'_1 = \frac{1}{J_1}\int i_1 dh_1 \quad - \quad - \quad - \quad - \quad (2)$$

since the action of the antenna current at a distance is determined by taking the sum of all the products (length of small portion of antenna)×(current in the portion). If the antenna has a large flat top the current i is practically equal through its whole height. Hence for this type $h' = h$. If the top is not flat the equation gives the height of a flat-topped antenna equivalent to the actual antenna. For an umbrella antenna h' is about equal to the height of the lower edge of the umbrella with one-third of the umbrella added. In the case of a linear antenna oscillating at its natural frequency $h' = 2h/\pi$, if oscillating at a longer wave-length, *i.e.*, if inductance be introduced, $h' = h/2$. The power in the receiving antenna produced by the voltage Eh_2 is $E \cos\phi \int i_2 dh_2$, if ϕ be the phase difference between i_2 and E. But $\int i_2 dh_2 = J_2 h'_2$, hence the power may be expressed as $Eh'_2 J_2 \cos\phi$. For resonance $\phi = 0$, $\cos\phi = 1$; hence if the resistance be R_2 we have $J_2 = Eh'_2/R_2$. Substituting the value of E given by equation (1) we obtain for the relation between the currents in sending and receiving antennas,

$$J_2 = \frac{377}{R_2} \cdot \frac{h'_1 h'_2}{\lambda r} J_1 \quad - \quad - \quad - \quad (3)$$

the current being uniform-alternating, and no allowance being made for dissipation of energy. Equation (3) is of the same form as that found by Austin from his experiments, except that to allow for dissipation of energy *en route* the factor $\epsilon^{-\frac{ar}{\sqrt{\lambda}}}$ must be added. The equation for uniform A.C. then stands—

$$J_2 = \frac{377}{R_2} \cdot \frac{h'_1 h'_2}{\lambda r} \cdot \epsilon^{-\frac{ar}{\sqrt{\lambda}}} \cdot J_1 \quad - \quad - \quad - \quad (4)$$

Barkhausen then shows that if the transmitted currents be damped, as in spark stations,

$$J_2 = \frac{377}{R_2\sqrt{1 + \frac{\delta_1}{\delta_2}}} \cdot \frac{h'_1 h'_2}{\lambda r} \cdot J_1 \cdot \epsilon^{-\frac{ar}{\sqrt{\lambda}}},$$

where δ_1 δ_2 are the logarithmic decrements. When this form is compared with Austin's actual measurements it is found that in these the theoretical maximum was practically reached, taking into account, of course, the conditions of experiment.

This theoretical research, therefore, gives a remarkably exact confirmation of Austin's results for the transmission for damped waves over sea, and indicates a reason for the superiority of uniform waves.

Marconi's Observations on Transmission Westward from Daylight to Darkness.—Mr Marconi has found that in transmitting across the Atlantic the signals are best when both stations are either in daylight or in darkness simultaneously. If the sun has risen at one station, but not at the other, or has set at the eastern, but not at the western, the signals are usually much weaker than at any other time. He has also observed that the best wave-length for transmission is not constant but varies from time to time.

It would seem that the first-mentioned phenomenon must be related to the varying thickness of the dielectric lower layer of the atmosphere, which is smaller where the sun is shining, and greater on the dark side of the earth. Thus the waves, generated at a station in daylight where the height of the dielectric is small, in travelling westward, pass into a deeper dielectric layer, *i.e.*, into a region where the conducting upper layer is farther from the earth. In the opposite direction the waves travel from a deep dielectric into a shallow one. In the region of transition from the one to the other the curvature of the upper conducting layer, *i.e.*, of the upper surface of the dielectric, must be greater than when the conditions are uniform all over the range. This may cause a greater dissipation of energy on the way. This might be accepted tentatively as an explanation were it not that the second observation appears to indicate that some type of resonance phenomenon is taking place which is interfered with by non-uniformity of the thickness of the dielectric layer.

The Effect of the Alps on Radiation.—Below is given an abstract of a portion of a paper by *P. Schwartzhaupt* in the *E.T.Z.* (see also *Electrician*, 26th August 1910), on abnormal distances of transmission. The results should be compared with those discussed above and below.

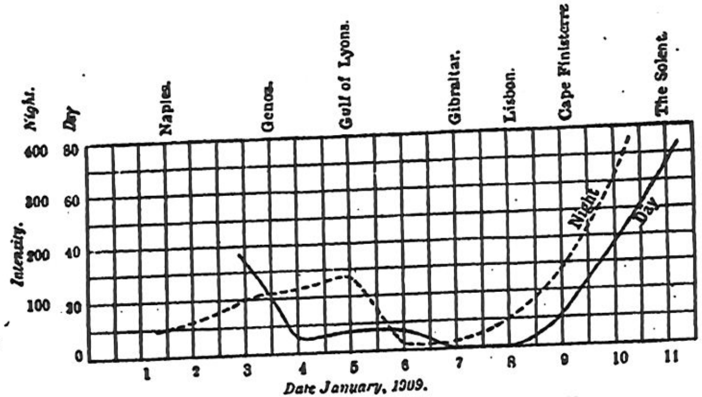


FIG. 183.—RECORD OF INTENSITY OF RECEIVED SIGNALS DURING A VOYAGE FROM NAPLES TO SOUTHAMPTON.

"An interesting series of observations was made on the s.s. 'Bremen,' during a voyage in the Mediterranean Sea, whilst receiving from the Norddeich station over the Alps. When leaving Naples, about 540 km. south of Genoa, telegrams could be received at night, with an intensity which we will denote by unity, next day 260 km. south of Genoa, the intensity had decreased to 0.65, rising at night in the harbour of Genoa to 2.4, and falling next day at the same place to 0.085. Thus, although the intensity in the day-time decreased as the ship approached the Alps, no such effect was observed at night.

"The variation in intensity for the whole journey is shown by the curves. The ordinates, which represent the intensity, are the ratios of the resistance of the telephone to that of a shunt across it; the latter being adjusted each time so that the signals could just be distinguished. The deep depression on the curves corresponds to the time of passing the Spanish mountains, illustrating the powerful deflecting or absorbing effect of mountains or forests. It may be noticed that the intensity at night was always sufficient to allow the telegrams to be received. At the place on the curves corresponding to the Gulf of Lyons there is a distinct maximum. Here it was found possible to signal to Scheveningen, a distance of 1,200 km., and it is striking that this favourable direction follows that of the Rhone Valley. It is also noteworthy that the Ushant station heard these signals of the 'Bremen,' this direction coinciding with that of the Garonne."

Further Observations by Mr Marconi.—In a recent lecture* at the Royal Institution Mr Marconi gives some interesting details of observations, extending over a year, made at Clifden on the strength of signals transmitted from Glace Bay. The average curve indicates a minimum about an hour and a half after sunset at Clifden, it being still daylight at Glace Bay. There follows a very marked maximum at the time of sunset at Glace Bay, *i.e.*, about four hours after sunset at Clifden. The signals then decrease in strength and are very irregular, during the night being occasionally very strong and occasionally much below the average. Just after sunrise at Clifden there is again a marked maximum, which is greater, as are all the variations, for a wave-length of 5,000 metres than for one of 7,000 metres. Within an hour and a half there follows a minimum, after which the signals return to average strength shortly before sunrise takes place at Glace Bay.

It is also noted that storms have a decided effect, and that moonlight may have an influence. Mr Marconi remarks that though in the day-time the range of communication appears to be the same in every direction, at night-time abnormally long ranges are often observed in a southerly direction, though not in a westerly direction, by ships near the southern coasts of the British Islands. Thus, for instance, low-power stations on the south coast communicate almost nightly with ships in the Mediterranean, although their day range is only about 150 miles. No such great increase occurs in westerly transmission. The same was found to be the case for very long distance transmission. Thus, while signals between Clifden and Glace Bay are on the average as strong by day as by night, signals from Clifden were obtained at Buenos Ayres by night only.

---

* *Electrician*, 11th August 1911.

Edwards' Observations on Day and Night Ranges.—In the report of the Canadian Naval Service Department for 1911, Mr C. P. Edwards, the General Superintendent, makes the following interesting remarks :—

"The peculiar phenomena affecting the range of wireless telegraph stations on the west coast has been very marked during the past year. It has been observed that between sunset and sunrise during the fall, winter and spring months, the range of the stations both for transmitting and receiving is increased from 300 to 500 per cent. The phenomenon is somewhat erratic. On some nights it is continuous, and constant communication can be maintained with another station within the zone, but on other nights it is intermittent and communication may be excellent for an hour when signals will suddenly fade away and then after a short period come on again. This may occur several times during the transmission of one message.

"The greatest distance over which communication has been established under these conditions is between Triangle Island and Honolulu, a distance of approximately 2,500 miles. The daylight range of the Triangle equipment is 400 miles.

"Another peculiar feature in connection with the above is that while the Victoria station is in communication practically every night with Ikeda Head 400 miles north, 250 of which are over high land, and with stations along the west coast of the United States as far down as San Diego, 1,000 miles south of Victoria, all of which is over high land, including Cascade Range and the Sierra Nevada, rising to a height of 15,000 feet, no improvement has ever been noticed in the communication between Pachena Point, B.C., and Victoria, B.C., 75 miles apart.

"No reasonable explanation for the same has yet been discovered. A systematic observance of the phenomenon is being made, and when more precise information is available there is no doubt some satisfactory explanation will be forthcoming."

Mr Edwards has also told me that with the smaller stations at first installed communication between Victoria and Pachena was practically impossible either by day or night although Victoria could communicate with Ikeda Head every night. Energy, therefore, reached Ikeda Head by passing high over Pachena without touching the latter on the way.

A Theory of Day and Night Ranges.—In 1908 I made the suggestions contained in the paragraph headed "Marconi's Observations . . ." for an explanation of the great variations in the range of a station so frequently observed during the night, and at sunrise and sunset. I shall now give a brief statement of what appears to be the theory of these differences as deduced from the facts reported by Marconi, Schwartzhaupt, Edwards, and others, in combination with what is known of the properties of the atmosphere.

The known facts as regards the difference between night and day may be summarised as follows :—

I. For stations working with waves less than 1,000 metres in length the range has been very frequently increased during the night by from 300 to 800 per cent. in the following localities and directions: (*a*) English Channel and North Sea to the Mediterranean, across sea and land, including the Alps, N.-S., N.W.-S.E. (G. Marconi, J. E. Taylor, P. Schwartzhaupt, and many others); Germany to West Coast of Africa, almost wholly over land, N.E.-S.W. (Telefunken Company). (*b*) Pacific Coast of British Columbia and United States, from Victoria and other stations over Cascade Range and Sierra Nevada (15,000 feet high), N.-S. (C. P. Edwards); between Norfolk, Virginia, and San Francisco, 2,000 miles over land, E.-W. (Austin).

II. Other observations mainly in regard to small power short-wave stations: (*c*) Long wave signals received at Buenos Ayres by night but not by day from Clifden and Glace Bay, although no day and night difference between Clifden and Glace Bay with the same wave-length (Marconi). (*d*) Transmission between Victoria, B.C., and Pachena Point, 75 miles distant over land, is equally difficult by day and night, but transmission from Victoria to Ikeda Head 400 miles further on, including 250 miles over land, is possible practically every night. The waves must pass almost over Pachena Point in reaching Ikeda Head at night, but no strengthening of signals at the former is observable (C. P. Edwards). (*e*) The working range, both day and night, is greater over the Central Pacific than over the North Atlantic (Japanese Naval observations, Poulsen Company, and others). (*f*) Stormy weather reduces range (Jackson, Wildman, Marconi, and others). (*g*) Longer ranges were obtained in South-West Africa than in Germany with the same apparatus (Flaskampf).

Now I draw the following conclusions from these observed facts:—

1. From (*a*) and (*b*) I conclude that the greatest percentage increases of range at night occur as a rule over land.

2. That increased night range is not limited to north to south directions but occurs in other directions, *e.g.*, Germany to West Africa, N.E.-S.W.; Norfolk, Virginia, to San Francisco, due E.-W.; Ireland to Mediterranean, N.W.-S.E.

3. I would hence suggest that it is a matter of average latitude and not direction which favours long night ranges.

4. From (*a*) and (*b*) and Marconi's Clifden to Glace Bay experiments, that the differences between day and night are much greater for short than for long waves.

The conclusions 1, 2, and 3 are new; 4 has already been known for some time, but I give it because it is essential to what follows.

Now it is well known from the work of Brylinski, Zenneck, Hack, Sommerfeld and myself that the distance of transmission over land depends essentially on the resistance and dielectric constants of the surface passed over, other things being equal. But these constants do not vary appreciably between day and night. Hence—

5. The enormous variations in range over land noted in (*a*) and (*b*) must be due to atmospheric conditions.

6. From (*e*), (*f*), and (*g*), taking into consideration the prevalent weather conditions as shown in Bartholomew's "Atlas of Meteorology," I conclude that the longest ranges, both day and night, are obtained with clear skies and uniformly fine weather, *i.e.*, with a settled and uniform condition of the atmosphere. The area between the west coast of America and Honolulu, for instance, is less cloudy than almost any other part of the globe, and it is there that the actual maximum range for a small power station appears to have been obtained.

III. As regards atmospheric conditions generally, it should be noted that Tesserenc de Borc has shown by observations that there exists all over the globe a quiet stratum of the atmosphere, the lower surface of which is at a height of from 10 to 16 km. There are, in fact, more or less uniform conditions in the upper atmosphere, storms and other meteorological disturbances being confined to the lower layers near the earth.

J. J. Thomson's experiments on the conductivity of air at low pressures show that at a height of about 55 km. the air has a high conductivity, equal, in fact, to that of a 25 per cent. solution of sulphuric acid. He proves also that there is a critical pressure at which the conductivity suddenly appears.

7. In a quiet and undisturbed atmosphere there is therefore a comparatively sharp surface of division between the non-conducting lower layer of the atmosphere and the upper layer of high conductivity. Along this surface the waves will travel without appreciable loss of energy just as over the sea.

8. A third point to be noted is that the ultra violet rays in sunlight produce ionization of the air, and consequently increase its conductivity. Now, loss of energy in the propagation of electric waves is a maximum in a partially conductive medium, just as in a leaky condenser. Hence during full daylight when these rays penetrate far towards the earth, the rising electric waves may be absorbed before reaching the highly conductive layer. The conditions in the lowest layer to which these rays hardly penetrate, will therefore be nearly the same during the day as if the upper conductive layer did not exist, *i.e.*, as if the waves were radiated freely into space.

9. Hence also at sunrise and sunset when the sun's rays are nearly tangent to the conductive layer its conductivity may be increased without any reduction of the sharpness of definition of its under surface.

10. From 8 we see that the Hertzian spherical wave theory, taking into account ground resistance, gives the theoretical *minimum*, and not the theoretical maximum as has hitherto been supposed.

11. From Edwards' observation (*d*) I conclude that the waves which reach Ikeda Head from Victoria during the night only, without showing any increase of energy at the intermediate station at Pachena Point, are waves which would have been absorbed by the ionized stratum below the conductive layer during the day-time. The variation cannot be due to an improvement in the conditions of the atmosphere near the earth, for, if so, the signals at Pachena would be strengthened; and they are not.

12. Barkhausen has shown that Austin's equation, deduced from his experiments for the relation between receiving and sending antenna currents, actually represents very closely the theoretical maximum on the spherical-radiation theory. Now the absorption of energy in passing over land is very much greater than in passing over sea, and wireless ranges by day over land are correspondingly less. They correspond in fact to the theoretical ranges deduced by Sommerfeld on the supposition that the atmosphere is practically homogeneous, and of very high resistance throughout. Thus the range over land on the assumption of a perfectly non-absorbing atmosphere might in fact be calculated from a formula like Austin's in which the exponential term was made such as to represent the large ground dissipation of energy.

13. Now many of the ranges attained over land at night would in theory require that there should be practically no absorption at all. For instance, Austin's formula applied to transmission between Norfolk and San Francisco would indicate such a condition. But the large ground absorption is always present, hence we are driven inevitably to the conclusion that there is some compensating action in the upper atmosphere at night, and that in these upper regions there is something which is better for transmission than the perfectly non-conducting atmosphere of the spherical wave theory.

14. Apparently the only thing which will give better transmission than perfect non-conduction in the upper atmosphere is a highly conductive layer sharply defined at

its lower surface. We are therefore led by reasoning from actually observed wireless phenomena to the same conclusion as has been reached by totally independent laboratory experiment, namely, that there is a highly conductive layer of air, the lower surface of which is comparatively sharp when not disturbed by ionizing rays or otherwise, and which commences at about 50 km. above the earth's surface.

15. *At night, therefore, transmission of energy to such ranges as* (*a*) *and* (*b*) *takes place mainly along the under surface of the highly conductive stratum of the atmosphere situated not more than* 55 *km. above the earth.*

16. The curious observation described in (*d*) is now very simply explainable. Pachena Point is only 120 km. from Victoria. The upper conductive layer is, say, 55 km. above them both. Hence if radiation from Victoria were to reach Pachena by reflection from the conductive layer it would have to leave the Victoria antenna at an upward angle of about 42 degrees, and be reflected from the conductive layer downwards to Pachena at the same angle. But both these are very unfavourable conditions, for, firstly, the density of radiation in this upward direction is small, and, secondly, reflection at so great an angle from a surface which is not a very sharply defined conductor involves much loss. There is little wonder, therefore, that the Pachena Point signals are no stronger by night than by day.

The conditions for Ikeda Head are quite different. Here the distance is 400 miles, hence the radiation which would reach the station by reflection from the upper layer leaves Victoria at an upward angle of only 10 degrees, and strikes the upper layer, and is reflected down to Ikeda Head at the same angle. The conditions here are therefore very much more favourable to transmission along the conductive layer. Whether the propagation actually follows the simple laws of reflection or whether it is a more complicated case which may more easily be considered as conduction, or refraction, is a matter of detail only.*

Conclusion.—Abnormally long ranges are thus due to transmission along, or reflection from, the under surface of the conductive layer of the atmosphere existing at about 55 km. above the earth. They are observable whenever atmospheric conditions are such that this under surface is sharply defined and smooth. Ranges equally great are obtained over land and sea with equal-powered stations, and the greatest ranges occur in fine weather and in the latitudes where the atmosphere is most settled.

---

* W. H. Eccles has suggested a possible physical explanation of the bending of the rays.

Moonlight, Effect on Signals.—Austen M. Curtis has found that at moonrise there is considerable variation in the strength of received signals, particularly when the moon is nearly full. Some details are given in his letters in the *Electrician* of 21st March and 2nd May 1913. He also gives the following data as regards the antenna at Amazonas, Brazil, and the stations which are audible at that station.

"The position of my station is about Lat. 2-52 N. 60-40 W. in the extreme northern part of Brazil, elevation about 200 metres. The country for about 70 miles all round is open and level, then closed in by dense forests and mountains on almost all sides.

"The aerial is 600 metres long, two wires, orientation N. and S., averaging about 5 metres above ground (about 12 above ground water), and the earth consists of several hundred metres of wire in the river Branco. The natural period is 4,000 metres. At this season of the year (February) the following stations can be heard regularly: *In the daytime*, Manáos, Marconi system, 360 miles south, 4,000 metres, about 50 kw., 30 to 40 times audibility; and Porto Velho, same as Manáos, 720 miles south, 2 to 10 audibility. *In the night*, Yquitos, Telefunken, 20 to 100 audibility; Lima, 1,700 metres, Telefunken, 1,250 miles S.W., up to 10 audibility; Santarem, Telefunken, 1,800 metres, 460 miles S.E., up to 20 audibility; Manáos, 1,350 metres, Telefunken, about 5 kw., up to 375 times audibility (average 200 audibility); Cape Cod, Mass., about 1,900 metres, 2,500 miles north, up to 15 audibility; Sayville, L.I., 1,800 metres, 25 audibility and 2,800 metres, 10 audibility, 2,500 miles north. Theoretically, this antenna, 120 times as long as high, should be extremely directive, but it does not seem to be at all so, at least at night."

Atmospherics.—One of the most frequent causes of trouble in wireless telegraphy is the occurrence of natural electrical disturbances which produce loud clicking and hissing sounds in the receiving telephones rendering the reading of signals very difficult, and at times impossible. The origin of these disturbances was to some extent uncertain until last year (1911) when I had the opportunity of listening to the atmospherics and at the same time observing a thunderstorm in the neighbourhood. Every visible flash of lightning was observed to produce an ordinary characteristic "atmospheric." Single knocks, double knocks, hisses, and the other well-known sounds were found to be produced by single flashes or by series of flashes in rapid succession, the sounds differing in no respect except strength from the "atmospherics" observed when no thunderstorm is near. The conclusion is therefore that atmospherics are, in general, the natural electric waves produced by lightning discharges. Their variation with the seasons and with the time of day is partly due to the actual seasonal and daily variations in thunderstorm frequency, and partly to the daily variation of transmissibility of electric waves over the earth's surface. In certain tropical districts, particularly in West Africa, thunderstorms occur practically every day of the year, hence there are plenty of sources from which atmospherics may come even without taking account of the less frequent storms in more temperate latitudes. It is probable also that when the air near the receiving antenna is so highly electrified as to cause brush discharges from the top of the antenna, sounds may be produced in the receiving telephone.

Many attempts have been made to devise methods for the avoidance of atmospheric troubles, but none so far with very great success. The "atmospheric" appears to be a much-damped wave train which excites the antenna by shock, leaving the antenna oscillating at its own natural frequency, hence it is therefore extremely difficult to cut out. If signals are strong it is possible, however, to reduce the strength of the atmospherics without very seriously reducing signals by putting the antenna slightly out of tune. Other methods, such as the Fessenden interference preventer, and the Marconi Company's use of two electric "valves" in parallel but in opposition, also give some relief.

J. E. Taylor suggests the use of small unearthed aerials of the Bellini-Tosi type in an interesting experimental paper read before the Institution of Electrical Engineers in 1910, and gives in the same paper the results of a large number of observations.

CHAPTER XVII.

WORLD-WAVE TELEGRAPHY.

MR TESLA in the year 1905 patented a system of wireless telegraphy and distribution of electrical energy which utilises the whole world as a conductor by the creation of stationary electric waves on it. In 1893 he suggested the possibility of doing so, in 1899 he claims that he discovered that such waves are produced by thunderstorms, and in 1906 he states that he has so far perfected his apparatus as to be able to produce them artificially.

What had previously been deduced theoretically in regard to such waves may be given in the words of one of our best known physicists, the late Professor G. F. Fitzgerald. In 1893 Professor Fitzgerald wrote * as follows:—

> "The period of oscillation of a simple sphere of the size of the earth, supposed charged with opposite charges of electricity at its ends, would be about $\frac{1}{11}$ of a second; but the hypothesis that the earth is a conducting body surrounded by a non-conductor is not in accordance with fact. Probably the upper regions of our atmosphere are fairly good conductors. . . . If we assume the height of the region of the aurora (*i.e.*, the upper conducting layer) to be 60 miles, or 100 kilometres, we get a period of oscillation of 0.1 sec. Assuming it to be six miles (or 10 km.), the period becomes 0.3 sec. . . . Dr Lodge has already looked for evidence . . . on the assumption that the period would be $\frac{1}{11}$ sec.; but with a negative result."

---

* *Nature*, September 28, 1893.

Sir Oliver Lodge's experiments were made at a period when the resources of the wireless telegraph receiver were unknown. Some years later Mr Tesla, having developed a sensitive wireless receiver capable of being tuned to jigs of any frequency, erected an experimental station at Colorado Springs, and spent many months in observing the electrical disturbances produced in the earth by the extremely violent thunderstorms which are common in that district.

Through the courtesy of Mr T. C. Martin, Editor of the *Electrical World and Engineer*, New York, I am enabled to make the following quotations from Mr Tesla's only publications on the subject. In 1893 Mr Tesla said: *—

> "Assume that a source of alternating currents be connected, as in Fig. 184, with one of its terminals to earth (conveniently to the water mains), and with the other to a body of large surface P. When the electric oscillation is set up there will be a movement of electricity in and out of P, and alternating currents will pass through the earth, converging to, or diverging from, the point *c* where the ground connection is made. In this manner neighbouring points on the earth's surface within a certain radius will be disturbed. But the disturbance will diminish with the distance, and the distance at which the effect will still be perceptible will depend on the quantity of electricity set in motion. Since the body P is insulated, in order to displace a considerable quantity the potential of the source must be excessive, since there would be limitations as to the surface of P. The conditions might be adjusted so that the generator or source S will set up the same electrical movement as though its circuit were closed. Thus it is certainly practicable to impress an electric vibration at least of a certain low period upon the earth by means of proper machinery. At what distance such a vibration might be made perceptible can only be conjectured. I have on another occasion considered the question how the earth might behave to electric disturbances. There is no doubt that, since in such an experiment the electrical density at

---

* "Inventions, &c., of Nikola Tesla," p. 348, T. Commerford (Martin, New York, 1893).

the surface could be but extremely small considering the size of the earth, the air would not act as a very disturbing factor, and there would not be much energy lost through the action of the air, which would be the case if the density were great. Theoretically, then, it could not require a great amount of energy to produce a disturbance perceptible at great distance, or even all over the surface of the globe. Now, it is quite certain that at any point within a certain radius of the source S, a properly adjusted self-induction and capacity device can be set in action by resonance. But not only can this be done, but another source S_1, similar to S, Fig. 184, or any number of such sources, can be set to work in synchronism with the latter, and the vibration thus intensified and spread over a large area, or a flow of electricity produced to or from the source S_1 if the same be of opposite phase to the source S. I think that beyond doubt it is possible to operate electrical devices in the city through the ground or pipe system by resonance from an electrical oscillator located at a central point. But the practical solution of this problem would be of incomparably smaller benefit to man than the realisation of the scheme of transmitting intelligence, or perhaps power, to any distance through the earth or environing medium. If this is at all possible, distance does not mean anything. Proper apparatus must first be produced, by means of which the problem can be attacked, and I have devoted much thought to this subject. I am firmly convinced that it can be done, and hope that we shall live to see it done."

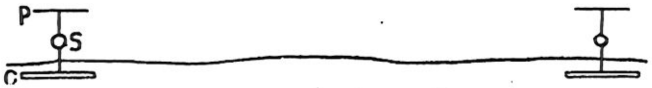


FIG. 184.—TESLA'S SUGGESTED WIRELESS TELEGRAPHY.

In March 1905, Mr Tesla, describing his Colorado experiments of 1899, mentions that one evening a violent thunderstorm had gathered in the mountains and drifted eastwards over the observing station. When it had passed, he continues :—

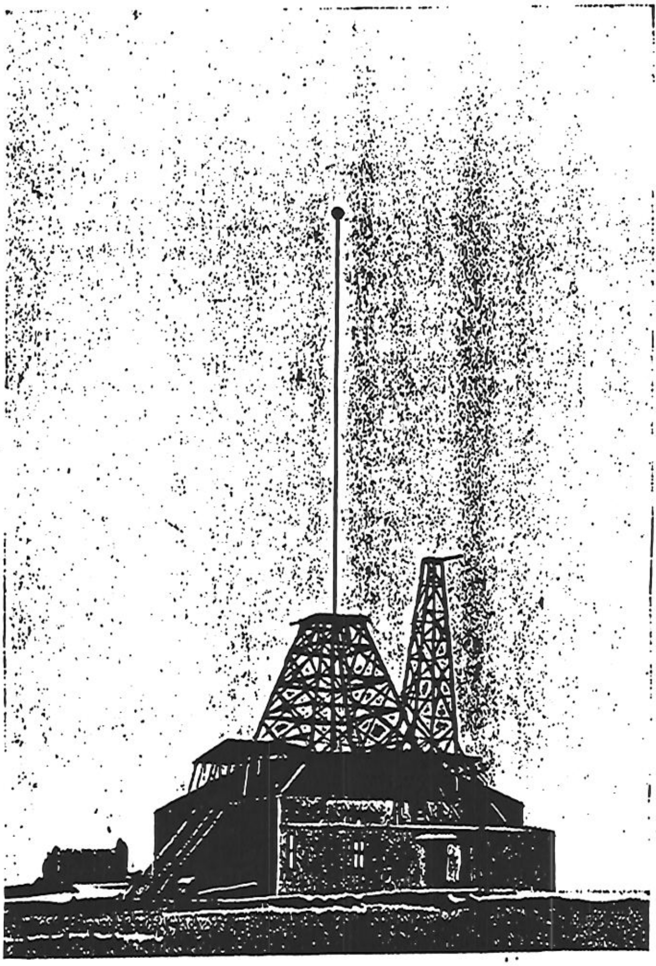


FIG. 185.—MR TESLA'S ELECTRICAL OBSERVATORY AT COLORADO SPRINGS.

"The recording apparatus being properly adjusted, its indications became fainter and fainter with the increasing distance of the storm, until they ceased altogether. I was watching with eager expectation. Surely enough, in a little while the indications began again, grew stronger and stronger, and, after passing through a *maximum*, gradually decreased and ceased once more. Many times, in regularly recurring intervals, the same actions were repeated until the storm, which, as evident from simple computations, was moving with nearly constant speed, had retreated to a distance of about 300 kilometres. Nor did these strange actions stop then, but continued to manifest themselves with undiminished force. Subsequently similar observations were also made by my assistant, Mr Fritz Lowenstein, and shortly afterward several admirable opportunities presented themselves which brought out still more forcibly and unmistakably the true nature of the phenomenon. No doubt whatever remained; I was observing stationary waves.

"As the source of the disturbances moved away the receiving circuit came successively upon their nodes and loops. Impossible as it seemed, this planet, despite its vast extent, behaved like a conductor of limited dimensions." *

The electric observatory is shown in Fig. 185.

The actual results of this investigation are described in the British Patent, No. 8,200 of 1905, from which I quote the following:—

"It has long since been known that electric currents may be propagated through the earth, and this knowledge has been utilised in many ways in the transmission of signals and the operation of a variety of receiving devices, remote from the source of energy, mainly with the object of dispensing with a return conducting wire.

"It is also known that electrical disturbances may be transmitted through portions of the earth by grounding only one of the poles of the source, and this fact I have made use of in systems, which I have devised for the purposes of transmitting through the natural media intelligible signals or power, and which are now familiar. But all experiments and observations heretofore made have tended to confirm the opinion held by the majority of scientific men, that the earth, owing to its immense extent, although possessing conducting properties, does not behave in the manner of a conductor of limited dimensions with respect to the disturbances produced, but, on the contrary, much like a vast reservoir or ocean which, while it may be locally disturbed by a commotion of some kind, remains unresponsive and quiescent in a large part or as a whole.

"Still another fact, now of common knowledge, is that when electrical waves or oscillations are impressed upon such a conducting path as a metallic wire, reflection takes place under certain conditions from the ends of the wire, and, in consequence of the interference of the impressed and reflected oscillations, the phenomenon of 'stationary waves,' with maxima and minima in definite, fixed positions, is produced. In any case the existence of these waves indicates that some of the outgoing waves have reached the boundaries of the conducting path and have been reflected from the same.

"Now I have discovered that notwithstanding its vast dimensions, and contrary to all observations heretofore made, the terrestrial globe may, in a large part or as a whole, behave towards disturbances impressed upon it in the same manner as a conductor of limited size, this fact being demonstrated by novel phenomena which I shall hereinafter describe.

"In the course of certain investigations which I carried on for the purpose of studying the effects of lightning discharges upon the electrical condition of the earth, I observed that sensitive receiving instruments, arranged so as to be capable of responding to electrical disturbances created by the discharges, at times failed to respond when they should have done so, and upon inquiring into the causes of this unexpected behaviour, I discovered it to be due to the character of the electrical waves, which were produced in the earth by the lightning discharges and which had nodal regions following at definite distances the shifting source of the disturbances. From data obtained in a large number of observations of the maxima and minima of these waves, I found their length to vary, approximately from 25 to 70

---

* *Electrical World and Engineer*, New York, March 5, 1904.

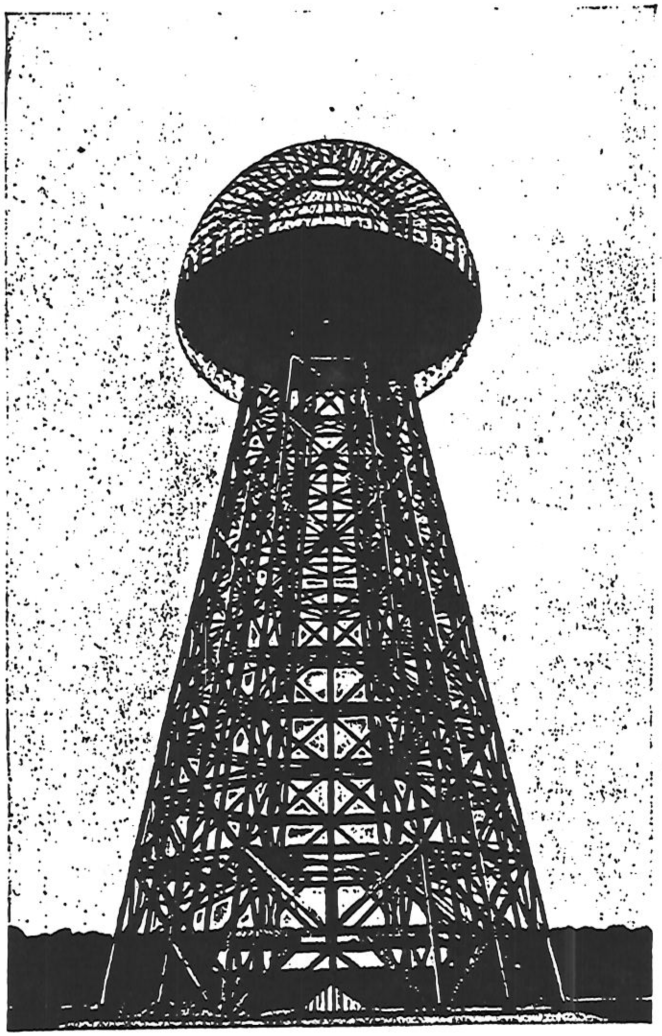


FIG. 186.—MR TESLA'S TRANSMITTING STATION ON LONG ISLAND.

kilometres, and these results and certain theoretical deductions led me to the conclusion that waves of this kind may be propagated in all directions over the globe, and that they may be of still more widely differing lengths, the extreme limits being imposed by the physical dimensions and properties of the earth.

"Recognising in the existence of these waves an unmistakable evidence that the disturbances created had been conducted from their origin to the most remote portions of the globe and had been thence reflected, I conceived the idea of producing such waves in the earth by artificial means, with the object of utilising them for many useful purposes for which they are or might be found applicable.

"This problem was rendered extremely difficult owing to the immense dimensions of the earth and, consequently, enormous movement of electricity, or rate at which electrical energy had to be delivered, in order to approximate, even in a remote degree, movements or rates which were manifestly attained in the displays of electrical forces in nature, and which seemed at first unrealisable by any human agencies. But by gradual and continuous improvements of a generator of electrical oscillations, which I have described in the Specifications of my United States Patents, Nos. 645,576 and 649,621, and in the Specification of my British Patent, No. 24,421 of 1897, I finally succeeded in reaching electrical movements, or rates of delivery of electrical energy, not only approximating but, as shown in many comparative tests and measurements, actually surpassing those of lightning discharges, and by means of this apparatus I have found it possible to reproduce whenever desired phenomena in the earth the same as or similar to those due to such discharges.

"With the knowledge of the phenomena discovered by me, and the means at command for accomplishing these results, I am enabled not only to carry out many operations by the use of known instruments, but also to offer a solution for many important problems involving the operation or control of remote devices which, for want of this knowledge and in the absence of these means, have heretofore been entirely impossible.

"For example, by the use of such a generator of stationary waves and receiving apparatus, properly placed and adjusted in any other locality, however remote, it is practicable to transmit intelligible signals; or to control or actuate at will any or all of such apparatus for many other important and valuable purposes, as for indicating wherever desired the correct time of an observatory; or for ascertaining the relative position of a body or distance of the same with reference to a given point; or for determining the course of a moving object, such as a vessel at sea, the distance traversed by the same or its speed; or for producing many other useful effects at a distance dependent on the intensity, wave-length, direction or velocity of movement, or other feature or property of disturbances of this character.

"I shall typically illustrate the manner of applying my discovery by describing one of the specific uses of the same, namely, the transmission of intelligible signals or messages between distant points, and with this object reference is now made to the accompanying drawings, in which—

"Fig. 187 represents diagrammatically the generator which produces stationary waves in the earth,

"Fig. 188 an apparatus, situated in a remote locality, recording the effects of these waves, and

"Fig. 189 the usual arrangement of the circuits of my receiving transformer.

"In Fig 187 A designates a primary coil forming part of a transformer, and consisting generally of a few turns of a stout cable of inappreciable resistance, the ends of which are connected to the terminals of a source of powerful electrical oscillations, diagrammatically represented by G. This source is usually a condenser charged to a high potential, and discharged in rapid succession through the primary, as in a type of transformer invented by me and now well known, having been described in my patents on apparatus of this kind, of which it will be sufficient to mention my British Patent, No. 20,981 of 1896. But when it is desired to produce stationary waves of great lengths an alternating dynamo of suitable construction may be used to energise the primary A.

"C is a spirally wound secondary coil within the primary, having the end nearer the latter connected to the ground E, and the other to an elevated terminal D. The physical constants of coil C, determining its period of vibration, are so chosen and adjusted that the secondary system E C D is in the closest possible resonance with the oscillations impressed upon it by the primary A. It is, moreover, of the greatest importance in order to still further enhance the rise of pressure and to increase the electrical movement in the secondary system, that its resistance be as small as practicable, and its self-induction as large as possible under the conditions imposed. The ground should be made with great care, with the object of reducing its resistance.

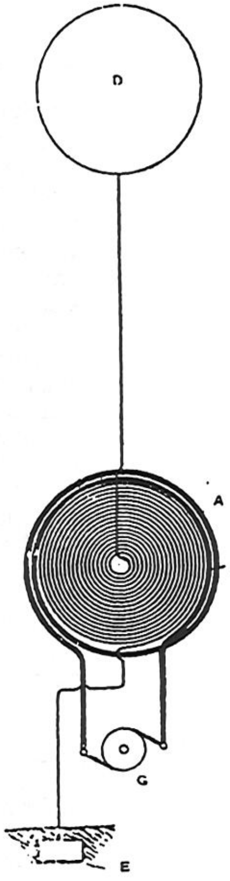


Fig. 187.

"Instead of being directly grounded, as indicated, the coil C may be joined, in series or otherwise, to the primary A, in which case the latter will be connected to the plate E. But be it that none, or a part, or all of the primary or exciting turns are included in the coil C, the total length of the conductor from the ground plate E to the elevated terminal should be equal to one-quarter of the wave-length of the electrical disturbance in the system E C D, or else equal to that length multiplied by an odd number. This relation being observed, the terminal D will be made to coincide with the points of maximum pressure in the secondary or excited circuit, and the greatest flow of electricity will take place in the same. In order to magnify the electrical movement in the secondary as much as possible, it is essential that its inductive connection with the primary A should not be very intimate, as in ordinary transformers, but loose, so as to permit free oscillation. That is to say, their mutual induction should be small. The spiral form of coil C secures this advantage, while the turns near the primary A are subjected to a strong inductive action and develop a high initial electromotive force.

"These adjustments and relations being carefully completed, and other constructive features indicated rigorously observed, the electrical movement produced in the secondary system by the inductive action of the primary A will be enormously magnified, the increase being directly proportionate to the inductance and frequency, and inversely to the resistance of the secondary system. I have found it practicable to produce in this manner an electrical movement thousands of times greater than the initial, that is the one impressed upon the secondary by the primary A, and I have thus reached activities or rates of flow of electrical energy in the system E C D, measured by many tens of thousands of horse-power. Such immense movements of electricity give rise to a variety of novel and striking phenomena, among which are those already described. The powerful electrical oscillations in the system E C D being communicated to the ground, cause corresponding vibrations to be propagated to distant parts of the globe, whence they are reflected, and by interference with the outgoing vibrations, produce stationary waves, the crests and hollows of which lie in parallel circles, relatively to which the ground plate E may be considered to be the pole. Stated otherwise, the terrestrial conductor is thrown into resonance with the oscillations impressed upon it just like a wire. More than this, a number of facts ascertained by me clearly show that the movement of electricity through it follows certain laws with nearly mathematical rigour. For the present it will be sufficient to state that the earth behaves like a perfectly smooth or polished conductor of inappreciable resistance, with capacity and self-induction uniformly distributed along the axis of symmetry of wave propagation and transmitting slow electrical oscillations without sensible distortion and attenuation. Besides the above, three requirements seem to be essential to the establishment of the resonating condition.

"1. The earth's diameter passing through the pole [*i.e.*, station] should be an odd multiple of the quarter wave-length, that is, of the ratio between the velocity of light and four times the frequency of the currents.

"2. It is necessary to employ oscillations, in which the rate of radiation of energy into space in the form of Hertzian or electro-magnetic waves is very small. To give an idea I would say, that the frequency should be smaller than twenty thousand per second, though shorter waves might be practicable. The lowest frequency would appear to be six per second, in which case there will be but one node, at or near the ground plate, and, paradoxical as it may seem, the effect will increase with the distance, and will be greatest in a region diametrically opposite the transmitter. With oscillations still slower the earth, strictly speaking, will not resonate, but simply act as a capacity, and the variation of potential will be more or less uniform over its entire surface.

"3. The most essential requirement is, however, that irrespective of frequency, the wave or wave train should continue for a certain interval of time, which I have estimated to be not less than one-twelfth—or probably 0.08484—of a second, and which is taken in passing to and returning from the region diametrically opposite the pole, over the earth's surface, with a mean velocity of about 471,240 kilometres per second.

"The presence of the stationary waves may be detected in many ways. For instance, a circuit may be connected directly, or inductively, to the ground and to an elevated terminal, and tuned to respond more effectively to the oscillations. Another way is to connect a tuned circuit to the ground and to two points lying more or less in a meridian passing through the pole E, or generally stated, to any two points of a different potential.

"In Fig. 188 I have shown a device for detecting the presence of the waves, such as I have used in a novel method of magnifying feeble effects, which I have described in my United States Patents, Nos. 685,953 and 685,955, and my British Patent, No. 11,293 of 1901. It consists of a cylinder C^2 of insulating material which is moved at a uniform rate of speed, by clockwork or other suitable motive power, and is provided with two metal rings B, B^1, upon which bear brushes A and A^1, connected respectively to the terminal plates P and P^1. From the rings B and B^1 extend narrow metallic segments G and G^1, which, by the rotation of the cylinder C^2 are brought alternately into contact with double brushes B and B^1, carried by, and in contact with, conducting holders H and H¹, supported in metallic bearings D and D¹, as shown. The latter are connected to the terminals T and T¹ of a condenser C, and it should be understood that they are capable of angular displacement, as ordinary brush supports. The object of using two brushes, as B and B¹, in each of the holders H and H¹, is to vary at will the duration of the electric contact of the plates P and P¹, with the terminals T and T¹, to which is connected a receiving circuit including a receiver R, and a device performing the duty of closing the receiving circuit at predetermined intervals of time, and discharging the stored energy through the receiver. In the present case this device consists of a cylinder D made partly of conducting and partly of insulating material E and E¹, respectively, which is rotated at the desired rate of speed by any suitable means. The conducting part E is in good electrical connection with the shaft G, and is provided with tapering segments F, F, F, upon which slide a brush K supported on a conducting rod L, capable of longitudinal adjustment in a metallic support M. Another brush N is arranged to bear upon the shaft G, and it will be seen that whenever one of the segments F comes in contact with the brush K, the circuit including the receiver R is completed, and the condenser discharged through the same. By an adjustment of the speed of rotation to the cylinder D, and a displacement of the brush K along the cylinder the circuit may be made to open and close in as rapid succession, and remain open or closed during such intervals of time, as may be desired.

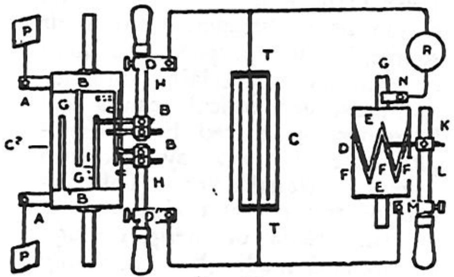


FIG. 188.

"The plates P and P¹, through which the electrical energy is conveyed to the brushes A and A¹, may be at a considerable distance from each other in the ground, or one in the ground and the other in the air, preferably at some height. If but one plate is connected to the earth and the other maintained at an elevation, the location of the apparatus must be determined with reference to the position of the stationary waves established by the generator, the effect evidently being greatest in a maximum, and zero in a nodal region. On the other hand, if both plates be connected to earth, the points of connection must be selected with reference to the difference of potential, which it is desired to secure, the strongest effect being, of course, obtained when the plates are at a distance equal to half the wave-length.

"In illustration of the operation of the system, let it be assumed that alternating electrical impulses from the generator are caused to produce stationary waves in the earth, as above described, and that the receiving apparatus is properly located with reference to the position of the nodal and ventral regions of the waves. The speed of rotation of the cylinder C² is varied until it is made to turn in synchronism with the alternate impulses of the generator, and the position of the brushes B and B¹ is adjusted by angular displacement, or otherwise, so that they are in contact with the segments G and G¹ during the periods when the impulses are at, or near, the maximum of their intensity. These requirements being fulfilled, electrical charges of the same sign will be conveyed to each of the terminals of the condenser, and with each fresh impulse it will be charged to a higher potential. The speed of rotation of the cylinder D being adjustable at will, the energy of any number of separate impulses may thus be accumulated in potential form and discharged through the receiver R upon the brush K coming into contact with one of the segments F. It will be understood that the capacity of the condenser should be such as to allow the storing of a much greater amount of energy than is required for the ordinary operation of the receiver. Since by this amount a relatively great amount of energy, and in suitable form, may be made available for the operation of a receiver, the latter need not be very sensitive. But, when the impulses are very weak, or when it is desired to operate a receiver very rapidly, any of the well-known sensitive devices, capable of responding to very feeble influences, may be used by the manner indicated or in other ways.

"Under the conditions described it is evident that during the continuance of the stationary waves, the receiver will be acted upon by current impulses more or less intense, according to its location with reference to the maxima and minima of said waves, but upon interrupting or reducing the flow of the current the stationary waves will disappear or diminish in intensity. Hence a great variety of effects may be produced in a receiver according to the mode in which the waves are controlled. It is practicable, however, to shift the nodal and ventral regions of the waves at will from the sending station, as by varying the length of the waves under observance of the above requirements. In this manner the regions of maximum and minimum effect may be made to coincide with any receiving station or stations. By impressing upon the earth two or more oscillations of different wave-length a resultant 'stationary' wave may be made to travel slowly over the globe, and thus a great variety of useful effects may be produced. Evidently, the course of a vessel may be easily determined without the use of a compass, as by a circuit connected to the earth at two points, for the effect exerted upon the circuit will be greatest when the plates P, P^1 are lying on a meridian passing through ground plate E, and will be *nil* when the plates are located at a parallel circle. If the nodal and ventral regions are maintained in fixed positions the speed of a vessel carrying a receiving apparatus may be exactly computed from observations of the maxima and minima regions successively traversed. This will be understood when it is stated, that the projections of all the nodes and loops on the earth's diameter passing through the pole, or axis of symmetry of the wave-movement, are all equal. Hence in any region at the surface the wave-length can be ascertained from simple rules of geometry. Conversely, knowing the wave-length, the distance from the source can be readily calculated. In like ways the distance of one point from another, the latitude and longitude, &c., may be determined from the observation of such stationary waves. If several such generators of stationary waves—

preferably of different lengths—were installed in judiciously selected localities, the entire globe could be subdivided in definite zones of electric activity, and such and other important data could be at once obtained by simple calculation or readings from suitably graduated instruments.

"The specific plan of producing the stationary waves, herein described, might be departed from. For example, the circuit which impresses the powerful oscillations upon the earth might be connected to the latter at two points.

"In collecting the energy of these disturbances in any terrestrial region at a distance from their source, for any purpose, and, more especially, in appreciable amounts, the most economical results will be generally secured by the employment of my synchronised receiving transformer. This invention, forming part of my system of transmission of energy through the natural media, has been fully explained in the patents first cited here, but for the better understanding of the present description it is diagrammatically illustrated in Fig. 189. Its most essential part is a circuit E^1 C^1 D^1, which is connected, arranged, and adjusted similarly to the transmitting circuit E C D and which is inductively linked with a secondary circuit A^1. The latter, it scarcely need be stated, may be wound with any desired number of turns, such as will be best suited for the operation of the device designated by M. The receiving transformer is closely attuned to the oscillations of the transmitting circuit, so that, irrespective of the length

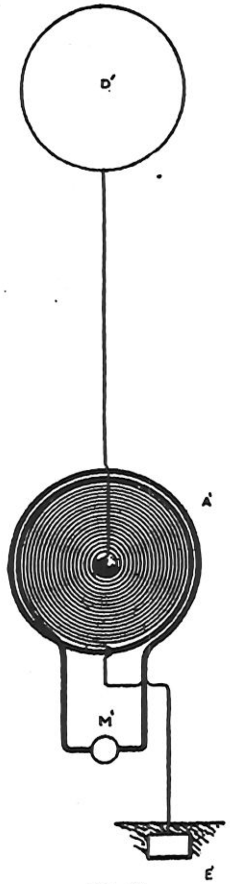


FIG. 189.

of the conductor E^1 C^1 A^1, the points of maximum potential coincide with the elevated terminal D^1, under which conditions the greatest amount of wave energy may be collected and rendered available in the secondary circuit A^1 for useful purposes.

"To complete this description, it may be stated that when it is desired to operate, independently, a great many receiving devices, by such stationary waves of different lengths, the principles which I have set forth in my British Patent, 14,579 (1901), and in my United States Patents, Nos. 723,188 and 725,605 (1903), may be resorted to for rendering the signals or quantities of energy intended for any particular receiver or receivers non-interfering and non-interferable

"In the above, I have briefly outlined my discovery and indicated only a few uses of the same, but it will be readily seen, that it is of transcending importance for the advancement of many arts and industries, new and old, and capable of innumerable valuable applications.

"Having now particularly described and ascertained the nature of this invention and in what manner the same is to be performed, as communicated to me by my foreign correspondent, I declare that what I claim is:—

"1. The improvement in the art of transmitting electrical energy to a distance which consists in establishing stationary electrical waves in the earth, as set forth.

"2. A system in accordance with Claim 1 which consists in producing in the natural conducting media, stationary electrical waves of predetermined length and operating thereby one or more receiving devices remote from the source of energy and properly located with respect to the position of such waves as herein set forth.

"3. The improvement in the art of transmitting electrical energy, which consists in producing in the earth stationary electrical waves of different lengths, varying their lengths, and causing thereby a resultant wave or effect to travel with the desired velocity over the earth, as above described.

"4. The method of producing effects at a distance, which consists in impressing upon the terrestrial globe stationary electrical waves, varying their characteristics and relations, and causing thereby corresponding effects in distant receivers, as above described.

"5. The improvement in the art of transmitting and distributing electrical energy, which consists in producing in the terrestrial globe intersecting trains of stationary electrical waves, establishing thereby regions of definite electrical activities, and collecting the energy, as above set forth.

"6. The method of producing electrical effects increasing with the distance, which consists in impressing upon the earth electrical oscillations of a frequency of about six per second, and of such character as to give rise to a stationary electrical wave, as set forth.

"7. The method of producing great electrical movements in the terrestrial globe, which consists in rendering it resonant by impressing upon it electrical waves of definite length and duration, as above specified.

"8. In the system as hereinbefore described for the transmission of electrical energy, generating apparatus adapted for producing a resonant condition in the terrestrial globe, as above specified.

"9. In the system as hereinbefore described for the transmission of electrical energy, a transformer adapted for the production of great electrical movements in the terrestrial globe, as above specified.

"10. In the system as hereinbefore described for the transmission of electrical energy, a source of primary electrical oscillations such as a condenser circuit and a secondary circuit inductively linked with the same and adapted for throwing the terrestrial globe into resonance, as above specified."

If Mr Tesla's statement that the fundamental electrical vibration of the earth has a frequency of six per second is founded directly on experimental evidence, and not merely on theoretical considerations, it is a proof that the earth is surrounded by a conducting shell, for if this were not so its lowest frequency of vibration would be seventeen per second, as mentioned by Professor Fitzgerald.

We can also make an estimate of the height at which the conductive layer commences, for calculation shows that since a height of 60 miles corresponds to a frequency of 10 per second, and a height of 6 miles to 3 per second, a frequency of 6 requires a height of about 35 miles, which is the same as that found from other data in Chapter XVI.

Thus we should have an entirely independent proof of the existence of a conducting layer in the atmosphere, and of the fact that the dielectric, with which we have to deal in wireless telegraphy, is a layer of air about 35 miles thick between two concentric spherical conductors.

Professor Fessenden has noticed in working between America and Scotland that there are apparently two impulses received for every spark, and has suggested that the second may come the longer way round the earth. The interval between them is approximately a fifth of a second, which would indicate the height of the upper conducting layer to be about 30 miles.

Professor Fessenden, however, does not agree with this explanation, but has not, as far as I am aware, suggested another.

CHAPTER XVIII.

ADJUSTMENTS, ELECTRICAL MEASUREMENTS, AND FAULT TESTING.

THIS chapter, like the rest of the book, is intended to contain useful hints and explanations for those who know and use wireless telegraph instruments.

Continuity of Conductors.—If the conductor is a closed or nearly closed circuit, its continuity may easily be proved by means of a cell and galvanometer of any type, or an electric bell; but if it be an open circuit such as an aerial wire, in which the conductor terminates in an insulating medium, other methods are more convenient. Aerial and earth wires are frequently covered with insulating material, a break in the conductor may therefore exist which is not visible on account of the insulation. If the broken ends of the conductor be only a small distance, say 2 or 3 mm., apart, there will be no difficulty in transmitting signals, but it will be impossible to receive any. If, therefore, you find that though your transmitting gear and receiver appear all right, you can get no answer from the other station, do not conclude that it is necessarily "his" fault, it may be your aerial.

A simple test, in such a case, is to hold the buzzer (an electric bell with the gong off, being a producer of electric jigs) near the aerial, and move it slowly along the aerial away from the receiver to which the aerial is kept connected. The receiver will respond to the buzzer as far as the aerial is continuous. It is most likely that, if a break does occur, it will be at a place where the wire is subject to repeated bending and unbending by the wind or other cause.

Insulation.—The first thing to note in wireless telegraphy is, the insulation does not insulate *per se*. That is to say, that a piece of insulating material, whose resistance to continuous currents may be millions of megohms, may be perfectly capable of transmitting the whole aerial wire current of a wireless station. It all depends on the shape.

If the insulator is a comparatively thin sheet between conducting plates the high frequency currents will pass through it, as a dielectric current, with as little loss as if it were a thick conductor. Thus what is usually known as a "condenser" may form part of any circuit which is intended to conduct high frequency currents only. Even a condenser of very small capacity such as may be made by twisting two short pieces of insulated wire together is not negligible and may transmit an appreciable current. I may mention two important cases. The first is, geometrically, on a large scale, and the second on a small one, their electrical dimensions are, however, not so very different. If a large sheet of conducting material, say wire gauze, or a metal cylinder a few feet in length and a foot or so in diameter, be suspended on insulators a foot or two above the ground, the condenser formed is capable of transmitting large currents, such as are used in transmission, if the frequency be high.

The second case illustrates what may occur in the receiving circuit of a station. If two insulated wires lie, or are wound side by side throughout a few inches, or feet, of their length, sufficient current may pass between them to actuate the receiver. Not, of course, a leakage conduction current but a dielectric displacement. In many problems in wireless telegraphy this has to be taken into account, but more particularly in the design of receiving transformers. It is easy to show that for instance an ordinary anti-inductive resistance need not act as a continuous conductor at all, and may conduct the current as well if the bight of the wire be cut as when the wire is continuous.

Insulation in wireless telegraphy means, then, not only high ohmic resistance but extremely small capacity between the insulated wire and the surrounding conductors, whatever they may be.

In ordinary language insulators must be very *thick*, *i.e.*, the distance between the conductors which are separated by the insulator must be large as compared with their areas.

Surface Leakage.—It is also important that any path from one conductor to the other over the surface of the insulator should be long, if high voltages are used, for otherwise sparks may travel along the surface and constitute a leak, even though the insulator is not pierced. In this connection it should be noticed that it is of little benefit to use a hooded insulator if the hood is merely screwed on, an uncovered rod of the same size as the centre piece would be quite as efficient. The spark travels up the film of air on the screwed part of the rod and thus through the hood without difficulty. Much useful information on this subject is contained in Mr Martin's book on Tesla's researches.

From what has been said it will be seen that ordinary insulation tests are useless, the only practical method being to subject the insulator to the working jig-current under the most disadvantageous circumstances as regards damp and dirt that are likely to occur in actual working.

It is often useful to wash outside insulators with fresh water to remove incrustations of salt, sand, and other materials which tend to reduce the insulating power of the surface.

Insulation of Transformers and Induction Coils.—As in the case of outside insulators, the breakdown of an induction coil or high tension transformer is usually of the disruptive kind. A hole is pierced through the insulation and a spark passes intermittently, whenever the potential rises high enough. By earthing alternately the ends of the secondary the position of the fault may often be roughly determined, as the longest spark will be obtained when the faulty end is connected to earth. As a rule the secondary must be taken to pieces and the leak discovered by examination. A temporary repair may sometimes be effected if necessary with paraffin wax (candles) and paper. Leaks of this kind are often due to a flaw in the ebonite or other insulating material, such as an air bubble or a particle of metal. It is therefore best to use oil, from which the air has been extracted, as an insulator, merely trusting to the solid insulator to keep the conductors at their proper distance apart. The breakdown may be largely due to heating owing to dielectric hysteresis, and this is much greater in solids than liquids. In addition, the liquid, even if pierced by a spark, is self-sealing, thus no precaution need be taken beyond slightly reducing the working voltage.

Receivers.—The testing of a receiver consists in (1) making sure that all its parts and connections are made as intended; and (2) in adjusting it on the aerial by the actual reception of signals from the sending station.

In tuned stations, *i.e.*, where the reception of signals depends on the receiving circuits having a definite natural frequency of vibration, it is usually necessary to adjust the aerial circuit to the proper frequency as a transmitter before inserting the receiver (see below).

So many detectors are now in use that it is impossible to go into the adjustments of them all, and indeed nothing but practical work can give a workmanlike knowledge of such a subject. I may mention, however, that it is frequently the subsidiary parts, such as relays or inkers, which give the most trouble, the distinctively wireless instruments, even the coherer, are usually more uniform in their action. This is, no doubt, one reason why detectors which work in conjunction with only a telephone receiver are now in so general use. In these receivers there is only the detector itself to adjust, and in many cases this is an exceedingly simple and practically permanent adjustment.

The testing of filings coherers has been gone into in Chapter IV., and methods of determining the sensibilities of several other types of detector have been given in Chapter VII.

Transmitters.—In most stations nowadays the most important adjustment is the equalisation of the frequencies of the aerial and condenser circuits, so that revibration may be obtained. This is usually done by putting a measuring instrument, say a thermo-ammeter between the aerial and earth, and then varying the inductance or capacity until a maximum current is obtained. The instrument may then be removed, if desired, and an equivalent conductor inserted in its place. The action of one circuit on another of the same natural frequency may cause, however, not one simple jig, but two of different frequencies and damping. The adjustment of frequencies, then, involves the finding of the greatest maximum current in the transmitting aerial, and the greatest maximum in the detector circuit. It should be remembered we are in general dealing with only three entirely distinct conducting circuits, the condenser circuit of the transmitter, the continuous or nearly continuous conductor formed by the aerials and the earth, and the detector circuit. Each of these circuits is broken as to continuous currents in one or more places (condensers), but each is complete as regards jigs, and is coupled to its neighbour electro-magnetically. The term circuit can, of course, be only applied in wireless telegraphy in its widest sense as implying a system of conductors along which a current impulse can pass directly. An inductive coupling is indirect as regards current, there being a transformation of the current energy in any desired proportion across space at right angles to the current; whereas if a condenser be interposed, the entire energy goes straight through it. We therefore do not include conductors coupled inductively as part of the same circuit, but we do consider that a condenser *connects* two conductors.

A hot-wire ammeter is used for the purpose of determining the point of maximum revibration between the circuits of the transmitter.

A convenient form of instrument is Duddell's thermo-ammeter, which is well suited for finding the maximum in the transmitter, while his thermo-galvanometer, a much more sensitive instrument, will determine the point of resonance of the receiving aerial to the transmitted jigs. There are, of course, many other suitable thermo-ammeters, but instruments as sensitive to jigs as the thermo-galvanometer are certainly not common (see Chapter VI.).

Beyond the tuning there is not much adjustment required in the transmitter. The spark length may have to be varied occasionally, and any moving parts of the apparatus seen to. If an induction coil be used the break will require some attention.

In the Lodge-Muirhead system the actual frequency of one of the circuits is determined by a wavemeter, and the other circuits are adjusted to the same frequency. Similar arrangements are used by other companies.

Interrupters.—The efficiency of an interrupter depends on the rapidity with which it breaks the circuit, on the maximum induction produced in core, and on its regularity in action. The rapidity with which the primary current is quelled determines the rapidity of the change of induction in the core, and hence the voltage attained by the secondary current. It is usual to shunt the spark, in the primary circuit, by a condenser, thus allowing the current to become oscillatory, and therefore to reach a zero value long before it would have otherwise done so.

Lord Rayleigh has shown that the condenser is not absolutely necessary to efficient working, if only a sufficiently rapid extinction of the primary current can be otherwise ensured. His plan, though perfectly satisfactory as a demonstration, was not exactly applicable to wireless telegraphy; in fact, he fired a rifle bullet at the primary wire. A wide gap was cut in the wire, and in an extremely small fraction of a second the current was stopped. The velocity of the bullet was probably about 2,000 feet per second—a velocity not attainable by ordinary mechanical arrangements, and therefore impracticable on induction coils. The experiment, however, proved that the rapid stoppage of the current was the essential factor in the production of a large secondary voltage. The best interrupter is therefore that which produces the largest and most rapid change of induction in the core, and which repeats the operation with the greatest regularity.

The adjustments should thus be aimed to keep these facts in view. The contact must be of long enough duration to allow the core to become magnetically saturated, or nearly so, and the break must be quick and regular. The wireless telegraphist does not require a shower of long thin, threadlike sparks, but a regular succession of short fat ones, which must crackle sharply and not fizz or flare.

Capacity.—Capacities in wireless telegraphy are usually very small as compared with what have hitherto been considered important. They also, as a rule, have to be reckoned for high frequencies which give different results from constant voltages, and as the stress in the dielectric is not steady but varying rapidly, the dielectric hysteresis of the insulator is not a negligible factor. That is to say, that the stress in the dielectric is not perfectly reversible; some of the energy is wasted and cannot be got back. The effect is like magnetic hysteresis, or like the imperfect elasticity of a solid, which on being bent or compressed does not return to its original shape entirely of its own accord. In all three cases the energy apparently lost is transformed into heat. The quantity of heat produced in each bending and unbending, or each to and fro of potential in the dielectric, is small, [illegible] the oscillations occur many hundred thousand times in a s[illegible]nd there is no time for the heat to radiate, and the dielectric may become so hot that it loses its insulating properties and is pierced by a spark discharge. Even much less rapid oscillations, if continued long enough, will break down a thick plate of glass.

The first occasion, as far as I am aware, on which experiments were made with a current of very high voltage, and also considerable horse-power, was at the Crystal Palace Electrical Exhibition in 1892. In Messrs Siemens' experiments an alternating current from an alternator, driven by a 25 H.P. engine, was transformed up to 50,000 volts. Terminals were placed at the middle points of opposite sides of a thick piece of plate glass over a foot square. When the current was turned on, the plate was lit up by a magnificent display of seaweed-like splashes of sparks running from each terminal over the central parts of the plate. In a very short time, however, the display ceased, and a small white spark was visible passing right through the plate between the terminals. On examination, after the current had been turned off, it was seen that a small hole had actually been melted through the glass. There was no crack, but a slight burring up of the glass round the hole, which itself was like the bore of a fine capillary tube. This showed that it was not mere mechanical strain which had caused the perforation, but that the glass had actually been heated by the continued alternating stresses until it had melted. Glass when heated rapidly loses its dielectric strength, hence after the central portion of the plate had become warm the current would rapidly concentrate itself and increase the heating until a puncture took place.

It is obvious that dielectric hysteresis such as this would cause serious loss of energy in a powerful wireless station, where the transmitting apparatus greatly resembles that used in the experiments quoted, the chief difference being in the frequency of the jigs in the condensers, those in the

wireless apparatus being, of course, of much the higher frequency. It has therefore been found advantageous in many cases to employ a dielectric such as air or oil, in which the hysteresis is practically inappreciable. Air under a pressure of 70 or 80 lbs. per sq. inch will withstand much higher potentials than at atmospheric pressure, and has for some years been used to increase the insulation, and therefore the available output of electrostatic machines. More recently it has been utilised by Fessenden and others to decrease the sparking distance for a given voltage in wireless stations, and Fleming and others have proposed its adoption as a suitable dielectric for condensers. It seems possible that where initial expense is not of the first importance, compressed air may take the place of other dielectrics in condensers through which a large dielectric current of high frequency has to be passed. Otherwise oil, particularly resin oil, carefully freed from air bubbles, is probably the best available insulator.

At his transatlantic stations, Mr Marconi originally used air condensers consisting of large metal sheets suspended, at several inches apart, in air at atmospheric pressure. These condensers take up much space, but are otherwise efficient and economical.

In spite of the advantages of oil, glass condensers, of the Leyden jar type, are in very general use in wireless telegraphy; their lightness and portability being much in their favour. Rather thin glass is used as a rule, as it is found to be more reliable, and when high voltages are required, a couple or more of the jars may be put in series, thus reducing the voltage on each.

A useful form is constructed of alternate sheets of glass and copper foil immersed in oil or vaseline, the latter giving the advantage of portability. For variable condensers air or oil is almost always used.

For condensers in the receiving circuit no such precautions against high voltages are necessary, and a thin layer of waxed paper or any similar dielectric may be used.

It must be remembered that the currents in the transmitter condensers sometimes attain very large values, occasionally hundreds of amperes; for this reason it is advantageous to use plates whose conductance is somewhat better than that of the old-fashioned tinfoil sheets; thin copperfoil serve[illegible] purpose well, and though it is rather more expensive [illegible] less easily worked into shape, the terminal connections are much more satisfactory and less liable to go out of order.

Fault-Testing—Condensers.—As in other insulation tests mere megohms are not sufficient. An indefinite number of these might be found lying in a condenser with a punctured dielectric, perfectly useless for wireless purposes, if only a low testing voltage (say 1,000 volts) were applied. It is essential to use at least the working voltage and frequency, and then to observe results. If there is a spark-gap in the testing circuit, the character of the spark or its absence will indicate whether the condenser is performing its function properly. Probably the best test would be to put the doubtful condenser in parallel with an adjustable spark-gap, and then increase the latter from nearly zero, *i.e.*, spheres nearly in contact, up to the required spark length. The voltages corresponding to a large range of spark lengths will be found in Tables X. and XI. It should be remembered that in revibrating circuits the voltages are occasionally really very high, even for wireless telegraphy. For instance, Professor Fleming speaks of sparks occurring at the top of an aerial, of a length which indicated a potential of seven million volts, when the aerial was excited by a closed jig circuit of equal frequency.

Condensers—Measurement of Electrical Dimensions.—There are many well-known methods of finding the capacity of a condenser when a steady voltage is applied. For instance, Lord Kelvin's method of mixtures. Descriptions and formulæ for such tests may be found in pocket-books of electrical rules and tables, such as Munro and Jamieson's, and in most text-books. Low frequency measurements do not, however, give accurately the high frequency capacity, hence it is necessary to employ high frequency currents when measuring accurately capacities used in wireless telegraphy.

Professor Rutherford, in 1896, made a number of determinations of the dielectric constant of various materials at high frequencies, using his magnetic detector as a current measurer. The results showed very considerable variations from ordinary steady voltage measurements. His method is of course applicable to the determination of the capacity of condensers.

Other methods, which are perhaps more suitable for the measurement of very small capacities, are based on the principle of Lodge's resonating Leyden jar circuits (see page 10). If the two circuits be tuned to one another, it is obvious that the equality of two capacities may be proved by putting first one and then the other in one of the circuits. If nothing else has been changed, the capacities must be equal if they give equally good resonance sparks. Thus any number of equal condensers might be obtained by the various combinations of which, in parallel and series, a standard of any desired value might be built up and used for the measurement of any unknown capacity. It is also clear that if the inductance and capacity of the primary circuit and the inductance of the secondary were known, and could be given definite values at pleasure, it would be possible to measure directly any capacity within the range of the instrument. Several instruments on this principle have been constructed, a convenient form being that designed by Professor Fleming, which, though it is mainly intended for the determination of jig frequencies, is suitable for the measurement of capacities such as are common in our branch of telegraphy. The instrument has been named a cymometer. We shall describe its use in considering the measurement of wave-lengths. The law which connects the capacity and inductance of a condenser circuit with its natural frequency of vibration is a simple one, at least to a first approximation, which is good enough for most purposes. If n be the frequency, or number of complete periods per second, while C is the capacity and L the inductance, in C.G.S. units, the equation $n=\frac{1}{(2\pi\sqrt{CL})}$ holds good. Thus if any two of these quantities be known, the third is easily calculable. We shall return to [illegible]er.

Dowse's Method for High Frequency Measurements.—The following method was given by Mr C. M. Dowse in the *Electrician* for 19th August 1910, in a paper on the use of thermo-junctions for high frequency current measurements :—

"Many useful applications can be made of the differential action of two equally sensitive junctions, and the writer has developed the method shown in Fig. 190, which enables low capacities to be balanced with ease and accuracy. A coil, A, which is in an oscillation circuit with capacities C_1, C_2 forms the primary of an oscillation transformer, the secondary B of which can be moved so as to vary the coupling. Connected to the terminals of B are an indicating instrument, I, and a pair of similar circuits each containing a variable condenser, K_1, K_2, and the primary coil of a small oscillation transformer, O_1, O_2. The secondary coils are in very close coupling and are joined to the terminals of the heating wires of two similar thermo-junctions. The junctions are in opposition and are connected to a sensitive galvanometer. The deflection is reduced to zero by balancing the variable capacities K_1, K_2, and the sensitiveness adjusted by varying the coupling between A and B. The indicating ammeter I shows the value of the current in the main circuit, and experiment will easily show the maximum value that can be reached without burning out the junctions. After noting the readings of the variable capacities, the capacity K_x to be measured is joined in parallel with one of the variable

condensers, and this latter varied until the deflection is again reduced to zero. The difference in the readings gives the capacity of the condenser K_x. It is advisable to partially withdraw B before inserting the test condenser in order to avoid overheating the junctions, and in case of differences in the calibrations of the junctions the heating circuits may be exchanged and the mean value taken. This precaution is unnecessary if the inductances of O_1 and O_2 are small, as the process is similar to the double weighing method of eliminating error. In an experiment made by this method, the capacities C_1 and C_2 were Leyden jars with capacities of 0.0012 mfd. each, and the coils A and B were of No. 16 copper wire wound on tubes 6 cm. and 4 cm. in diameter. C_1 and C_2 were moving sector variable air condensers, and the oscillation transformers in the condenser circuits were of No. 16 copper wire — primary eight turns, secondary four turns, one winding over the other. The junctions were of iron and constantan, and a Paul unipivot galvanometer was used. A change of 0.8 per cent. in the capacity was easily detected, and with a reflecting galvanometer this sensitiveness could be considerably increased."

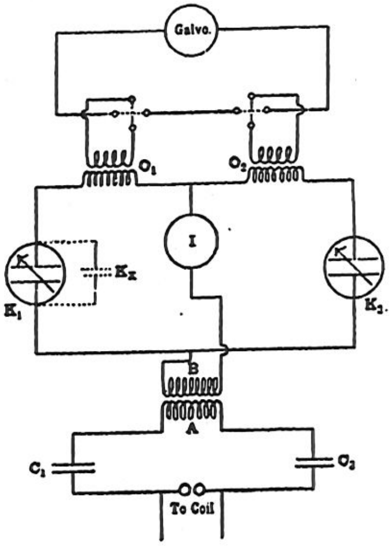


FIG. 190.—DOWSE'S METHOD OF MEASUREMENT.

If K_x be greater than K_1 or K_2, it is clear that Mr Dowse's method can still be used by putting a known capacity K_y in series with K_x. Their combined capacity K_z, as read from K_1, is then,

$$K_s = K_x K_y/(K_x + K_y), \text{ giving } K_x = K_y K_s/(K_y - K_s).$$

The method, being a zero method combined with simple substitution, may also be applied to the measurement of inductances and resistances. Thus, if equal inductances L_1, L_2 be introduced between K_1 and O_1, and K_2 and O_2 respectively, the circuit may be balanced, and an unknown L_x measured by putting it in place of a portion of L_1. The same is true for straight wire resistances.

Measurement of Resistance at High Frequencies.—Lindemann[*] has made a large number of determinations of the high frequency resistance of standard and solid wires by the following method:—

An oscillating circuit was made up out of the wire to be tested in series with a variable condenser. This was coupled loosely to a high frequency current generating circuit, usually containing a Poulsen arc, on the one hand, and to a measuring circuit containing a thermo-junction and galvanometer on the other. Readings of the maximum resonance currents i_0 i_1, with and without an additional known resistance R in the oscillating circuit give the value of the unknown resistance x as

$$x = \frac{R}{\frac{i_0}{i_1} - 1}.$$

The most remarkable result obtained was the proof of the futility of using stranded wire in which the strands were insulated only with a thin coating of enamel. In one case, for a wave-length of 300 metres, the resistance of the stranded wire was 58 per cent. greater than that of a solid wire having the same cross-sectional area of copper. With proper insulation between the strands, however, stranded wires give low resistances.

Professor Fleming has also devised a method for the measurement of high frequency resistances by balancing their rises of temperature in a species of differential air thermometer (*I.E.E. Journal*, 1908).

---

[*] *Jahrbuch der drahtlosen Telegraphie*, Bd. 4, Hft. 6.

Relays.—A relay of one kind or another is used in many systems of wireless telegraphy; indeed we might include almost all detectors whether coherers or otherwise under the head of relays, for their function is usually that of a relay. However, since it is convenient to deal with them separately, we shall limit the term to the older type of electro-magnetic relay. At the same time it should not be forgotten that all detectors except the rectifiers are in reality jig relays, *i.e.*, they are actuated by the electric jig and turn on the current of a local battery.

The ordinary telegraphic relay consists of an electro-magnet, the windings of which are connected to the line from the distant station. As the line current increases the magnetisation of the electro-magnet, a ditton, or tongue, of soft iron, is pulled over and makes contact with a stop, thus completing the circuit of the local battery. It is clear that in the adjustment of a relay we have to deal with two most difficult experimental problems. Firstly the ditton must move sharply over under the influence of a very slight change in the magnetic field, and it must return as rapidly when the field returns to its normal value. It is therefore not possible to gain sensibility by making the controlling forces such that the ditton is in nearly unstable equilibrium; for if that were done the return movement would be uncertain and slow. The best working conditions with most relays appear to be attained when the tongue is held back by a somewhat stiff helical spring, and has therefore only a very small range of motion altogether.

If a relay is to act rapidly it is clear that the mass of the moving part must be small, and that the controlling spring must be a comparatively stiff one. The reason for a stiff spring is that otherwise it is very difficult to set the contacts very close together, and still avoid disturbance also making the light moving arm of springy material. When the position and strength of the springs is correctly adjusted, both yield slightly when the arm strikes the contact, and this not only diminishes the rebound by softening the blow, but also prolongs the contact by following up the return movement. A very neat adjustment is provided for the fixed springs, one screw shifting a slider which alters the effective length of the spring, and another swinging the carriage on which the spring is mounted. A contact system is provided at each side, so that it is immaterial which way current is sent through the instrument. Another interesting detail is the provision of a stop limiting the return movement of these springs, so that all possibility of sticking is avoided.

"The moving coil is mounted between top and bottom suspensions of phosphor bronze strip, and is fully damped electro-magnetically, and balanced for use on board ship. As in the case of the Sullivan 'speaking' galvanometer for submarine cable work, the frame carrying the coil suspension and relay contacts can be bodily removed by sliding out ve lly, and as the connections to both the line and local uits are made by stout springs bearing on pillars, a new l can be substituted in a few seconds in case of a suspension becoming defective, or a coil otherwise damaged. The whole instrument is simple, strong, and not liable to be affected by vibration, notwithstanding its high degree of sensibility.

"Although primarily designed as a call relay, the apparatus would seem capable of recording signals at slow speeds at distances considerably in excess of those already accomplished with recorded signals, but experiments in this direction have not yet been carried out. In addition to the relay contacts the instrument is provided with a mirror, so that if desired a visual signal can be made by the movement of a large rectangular 'spot' of light on a wall or bulkhead of the ship. The movement of a large spot of this kind would be visible to all in the room without close watching, and a useful check would be provided in the case of an accidental interruption of the local bell circuit. Mr Sullivan is a firm believer in the advantages of the 'electrolytic coherer' over other detectors, and is perfecting several pieces of apparatus designed to work with this system."

An interesting type of relay, not as yet used in wireless work, is the magnifying relay invented by Mr S. G. Brown. It consists of two movable coils mounted on one axis, the lower one being in the field of, and being actuated by, the line current, and the upper one in a powerful alternating field locally produced. The upper coil is connected with a rectifier. When no current is flowing in the lower coil the upper stands with its plane parallel to the lines of magnetic force. When a current turns the lower coil, the upper turns with it and therefore allows lines of force to pass through it, and as these are alternating, a considerable alternating current is generated by induction in it. This current is passed through the rectifier and from thence through the recording instrument. The instrument is most ingenious, and does away with contacts, but is unfortunately rather complicated. In 1910 Mr Brown invented a type of telephonic relay of great sensitiveness, which has the power of making audible telephonic currents which would otherwise be inaudible. It is of considerable use in magnifying received signals where these would otherwise be too faint to read. It is in use at a number of the Marconi Company's stations.

Audibility of Signals.—A measure of the strength of signals may be obtained by the following method: Adjust the receiving circuit and detector to give maximum loudness in the telephone. Now shunt the telephone (only) by a variable resistance, and adjust this until the signal just becomes audible. The audibility may then be expressed as

$$A = \frac{r+t}{r},$$

where r is the shunt resistance for just audible signals and t is the telephone resistance. Austin remarks that with care a series of measurements of intensity may be got to agree among themselves to within about 10 per cent. For accurate results, therefore, a considerable number of readings should be taken and an average struck.

Measurement of Frequency and Wave-Length.—Since the frequency of oscillation of any circuit or conductor depends upon its inductance and capacity, it is possible by determining these to obtain its value. Various instruments are now made in which a variable and graduated condenser is combined with an adjustable inductance, so that the oscillation frequency of the circuit of the instrument can be obtained from the readings. The instrument is then placed so that a part of its circuit is in proximity to the circuit whose frequency it is desired to measure. A jig current is then started in the undetermined circuit, and the instrument is adjusted until a thermo-galvanometer or other indicator on it shows a maximum induced current. This occurs when the natural frequencies of the circuits are the same, it is therefore only necessary to calculate this frequency from the values of capacity and inductance shown by the instrument.

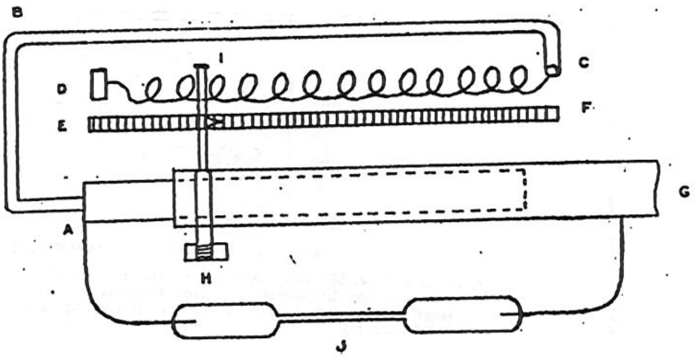


FIG. 191.—FLEMING'S CYMOMETER.

A B C, Thick C Co-axial Capacity Conductor; *C D*, Helix used as Variable Inductance; *E F*, Scale; *A G*, orming Variable Condenser; *H I*, Slider which varies Inductance and taneously; *J*, Vacuum Tube to indicate Maximum Resonance.

The simplest form of wavemeter is a variable condenser of the multicellular type in circuit with a coil or rectangle of wire of known inductance and a thermo-ammeter of any convenient type, such as the Snow Harris. By having a set of coils of different inductances, the range may be increased. The Donitz "ondameter" is of this type (Fig. 192).

In the type of instrument designed by Professor Fleming, the movement of one handle varies the capacity and inductance proportionately; it is therefore possible to graduate the instrument, which Professor Fleming has named a cymometer, uniformly in terms of frequency. This is a convenience for rapid determinations, but limits, in some respects, the general utility of the instrument; it is well suited, however, for the measurements usually required in wireless telegraphy. Fig. 191 shows the instrument diagrammatically, and except in regard to the mechanical connection of the capacity with the inductance, and the neon tube used as an indicator, the diagram would apparently be also a correct representation of the wavemeters used by other companies.

An instrument of this kind may be used, of course, to determine any one of the quantities in the equation $n=\frac{1}{2\pi\sqrt{CL}}$, provided the other two are known. For instance, if the capacity of a condenser has to be found, it is only necessary to put it in circuit with a standard inductance, and then determine the frequency of the circuit so formed by means of any wavemeter. An unknown inductance may likewise be measured by putting it in series with a known capacity. This is in fact probably the most accurate way of determining either quantity, as measurements of capacity taken at steady voltages are not correct for jigs, and the inductances used in wireless telegraphy are as a rule so small that measurements by other methods are very difficult.

If a helix be long in proportion to its diameter, its inductance may be approximately determined by the formula $L=l(\pi dn)^2$; where L is the inductance, l the length of the helix, d its diameter, and n the number of turns per unit length. For instance a helix of 5 cm. diameter, 50 cm. long, and 2 turns per cm., would have an inductance $L=50(3.14 . 5.2)^2 = 50 . 1{,}000 = 50{,}000$ C.G.S., or 1,000 per cm. of its length, approximately.

The capacity of a condenser formed of two concentric metal cylinders, which is a convenient form in which to make a variable standard, is given by the equation

$$K=S\frac{l}{2\log_e\frac{R}{r}}$$

where K = capacity in C.G.S. electrostatic units (these may be converted to microfarads by dividing by 900,000); R and r are the radii of the external and internal cylinders respectively in cms.; S is the specific inductive capacity (dielectric constant) of the insulator between the cylinders; l is the length in cms. of the part of the cylinders which overlap—this, in the case of a variable condenser in which the variation is produced by drawing one cylinder partially out of the other, is subject to a small correction.

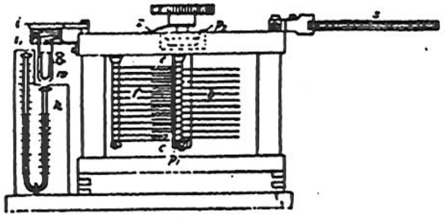


FIG. 192.—THE DÖNITZ WAVEMETER. (*Elevation.*)

s, Inductance; *b*, Movable, and *f*, Fixed Plates of Variable Condenser; *i*, Single Turn of Wire coupling Condenser Circuit loosely to Thermo-Ammeter *i*, *w*, *h*, of Snow Harris Type. Several interchangeable inductances of various magnitudes are used to increase the range of the Instrument.

Thus the capacity of two cylinders overlapping one another throughout 50 cms. of their length, whose radii are 2 and 2.2 cms., separated by an ebonite tube (dielectric constant = 3), with walls .2 cm. thick, is approximately—

$$K=\frac{50 . 3}{2\log\left(\frac{2.2}{2}\right)}=\frac{150}{2\times .0953}$$

$$K=778 \text{ C.G.S. electrostatic units.}$$

$$=\frac{778}{(3 . 10^{10})^2} \text{ C.G.S. electro-magnetic units.}$$

$$=0.00087 \text{ microfarad.}$$

The frequency of a circuit containing no appreciable capacity or inductance beyond those of the above condenser and helix and no resistance, would be—

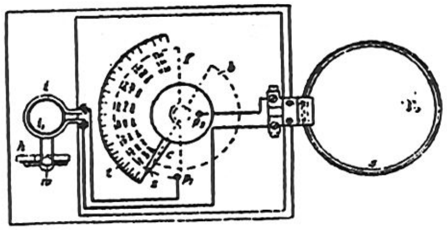


FIG. 193.—THE DÖNITZ WAVEMETER. (*Plan.*)

s, Inductance; *b*, Movable, and *f*, Fixed Plates of Variable Condenser; *i*, Single Turn of Wire coupling Condenser Circuit to Thermo-Ammeter *i*, *w*, *h*. The scale *t* gives wave-lengths; the three rows of numbers corresponding to small, intermediate, and large inductances (*s*).

$$n=\frac{1}{2\pi\sqrt{.00087\times 10^{-15}\times 10^4}}$$

$$=\frac{1}{6.28\sqrt{87\times 10^{-16}}}$$

$$=\frac{10^8}{6.28\times 9.34}$$

$$=1.71\times 10^6;$$

or nearly two millions per second.

In the Fleming cymometer the frequency and wave-length may be read directly from the scale. In wavemeters in which the condenser and inductance are not simultaneously varied, separate wave-length scales, corresponding to the standard inductance coils, are provided.

It is clear, then, that the frequency of any circuit may be calculated if its capacity and inductance are known, or it may be found by resonance with a circuit of known capacity and inductance.

An ingenious direct reading frequency meter invented by Commander Ferrié was put on the market by Carpentier of Paris in 1910. By transposing the well-known equation $\gamma = E/\sqrt{R^2 + \omega^2 L^2}$, we obtain ω as a function of γ and E, R, and L being constants. Hence an ammeter in series with an inductance, in parallel with a voltmeter in series with a resistance will indicate the value of ω, the frequency, by the point of intersection of their pointers, if the instruments be placed side by side. The Ferrié instrument is constructed on this principle.

Damping.—The oscillatory current produced by the sudden breakdown of the resistance of the spark-gap when the spark occurs gradually dies out, partly through the conversion of the energy stored in the charge into heat, and partly by radiation. By radiation we do not mean, in this connection, only straight line radiation through free space, but also the oscillatory currents which spread out over the earth's surface. These also are finally damped out by the resistance of the earth and the surrounding air.

The rate of damping of the jig in a transmitter is, of course, a very important factor, and its determination is necessary before the efficiency of the installation can be known. In this country the damping is usually defined as the ratio of the amplitude of the second half-oscillation to the amplitude of the first half-oscillation, *e.g.*, of the first negative to the first positive wave if we begin with a positive. Abroad the number usually expresses the ratio of the second positive to the first positive, *i.e.*, the loss

by damping is reckoned over the complete oscillation. The Napierian (or hyperbolic) logarithm of the reciprocal of the damping, *i.e.*, of the ratio First Amplitude : Second Amplitude, is called the logarithmic decrement of the motion.

Several experimental methods are available, of which I shall describe three. Professor Rutherford's method of determining the coefficient of damping of an electrical oscillator is as follows:—

The oscillatory currents are made to pass round a very small helix of fine wire in the axis of which is placed a small steel needle or bundle of fine steel wires, which has been magnetised to saturation. The deflection of a suspended magnet or magnetometer caused by the steel needle when placed at a given distance is noted. The needle is then placed in the helix, and the oscillatory current passed through the latter. The change of magnetisation of the needle is noted by an observation with the magnetometer as before; call this result (A).

The needle is then remagnetised to saturation, and after a measurement with the magnetometer, is placed in the helix in the reverse direction. A spark is passed, and another measurement (B) of the change of magnetisation made. These changes in magnetisation are proportional to the amplitudes of the first and second half waves, hence from these observations the damping and logarithmic decrement may be calculated. There are, of course, other methods, but this is one of the simplest to carry out, and appears to give very satisfactory results.

Lieutenant Tissot,* using a wavemeter with constant inductance and variable capacity, first determines the frequency N of the given circuit. Leaving the wavemeter equifrequent with the circuit under test he next introduces non-inductive resistances (short straight wires from 0 to 3 ohms) in its circuit and observes the reading of the thermo-galvanometer corresponding to each resistance. On plotting the resistances as abscissæ and the currents as ordinates, a straight line is obtained, which on being produced cuts the axis of X in some point whose abscissa is, say, x on the scale chosen. By multiplying x by $1/2LN$, where L is the inductance of the wavemeter, the value of $\delta/2+\delta'$ may be obtained; δ being the logarithmic decrement of the main circuit and δ' that of the wavemeter. The latter is usually small in comparison with the former and may generally be neglected; hence x/LN is approximately equal to δ, the decrement required.

---

* *Soc. Int. Elect. Bull.* 6, July 1906.

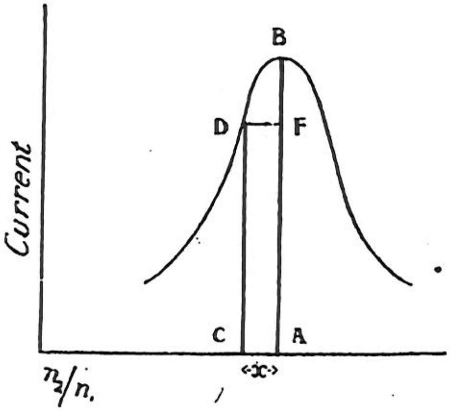


FIG. 194.

Determination of Damping from Resonance Curve.—In Fig. 194, in which the maximum value of the current is taken as unity, draw an ordinate CD at a small distance x from AB the maximum ordinate. Then it may be shown* that the sum of the decrements of the primary and secondary circuits, per period—

$$\delta_1+\delta_2=2\pi x\frac{\gamma}{\sqrt{\gamma_r^2-\gamma^2}}$$

---

* J. Zenneck, "Elektromagnetische Schwingungen," p. 570 (Enke, Stuttgart, 1905).

γ_r being current for resonance and γ current at x, or

$$\delta_1+\delta_2=2\pi AC\frac{FA}{\sqrt{(AB)^2-(FA)^2}}.$$

It is therefore possible to calculate directly the damping of the circuit from the resonance curve obtained by the application of a uniform H.F. alternating voltage, since, for this, δ_1 vanishes. If a uniform H.F. current cannot be used, the decrement, δ_2, of the resonating circuit may be made negligibly small in comparison with δ_1, and hence δ_1 obtained. Otherwise, known resistances must be interposed (see Tissot's method).

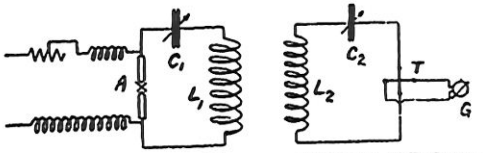


FIG. 195.—DETERMINATION OF DAMPING BY UNIFORM H.F. CURRENT (VON TRAUBENBERG AND MONASCH.)

A, Poulsen Arc; C_1, C_2, Variable Condensers; L_1, L_2, Inductances; T, Thermo-junction; G, Galvanometer.

Brandes' Method.—A simpler method, which does not involve the calculation of n_1/n_2, but proceeds directly from the measured quantities, *i.e.*, the current and capacity, has been given by H. Brandes,* and experimentally illustrated by Von Traubenberg and Monasch.† It may be carried out as follows:—

Find the resonance current and resonance capacity; then alter the capacity, making it first less and then greater than the resonance value, making the alteration in each case such that the (current)^2 falls to the same fraction, say .75, of its resonance value. The sum of the decrements of the coupled circuits is then

$$\delta_1+\delta_2=K\frac{C_2-C_1}{C_0},$$

---

* *Ann. d. Physik*, 1907, 22, p. 640.

† *Phys. Zeitschr.* 8, p. 925, December 1907.

where K is found from Brandes' table, and (see Chapter XXI.) varies with the fraction chosen.

With the ratio $(\gamma/\gamma_r)^2=.75$, as suggested above, the result is

$$\delta_1+\delta_2=2.72\frac{C_2-C_1}{C_0}.$$

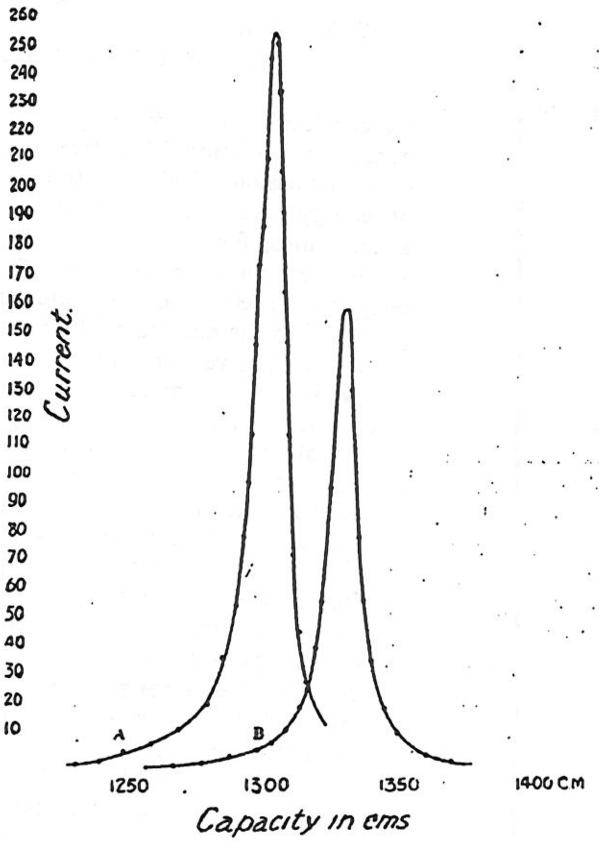


FIG. 196.—EACH CURVE REPRESENTS THE VARIATION OF CURRENT IN A CIRCUIT ON WHICH A UNIFORM H.F. VOLTAGE IS IMPRESSED, WHEN THE CAPACITY IN CIRCUIT IS VARIED. (VON TRAUBENBERG AND MONASCH.)
One of the Circuits, *B*, had greater inductance and resistance (Damping) than the other, *A*.

From this, if δ_2 be small, we have the approximate value of δ_1; or if δ_1 is very small, of δ_2. The decrement per whole period of the primary circuit can be calculated from the formula, $\delta_2=R_2/2NL_2$; where R_2 and L_2 are resistance and N the frequency. Hence, if Brandes' method be applied,

$$\delta_1=K\frac{C_2-C_1}{C_0}-\frac{R_2}{2NL_2}.$$

Use of Uniform H.F. Current.—Von Traubenberg and Monasch employ a uniform H.F. current generated by a Poulsen arc in the primary circuit, *i.e.*, $\delta_1=0$. Hence δ_2 is found directly from $\delta_2=K\frac{C_2-C_1}{C_0}$ to a very close approximation. Fig. 195 shows the method of operation, and Fig. 196 two resonance curves obtained. The abscissæ are values of the capacity, and the ordinates, being galvanometer readings, are proportional to the square of the current in the secondary or resonating circuit.

In Fig. 196 the damping was altered from the one to the other value by inserting an extra inductance. When the damping due to the resistance of the thermo-junction is known, it is possible to calculate the actual damping of the rest of the circuit from the observed total value. A better method is to have the thermo-junction and galvanometer in a separate circuit, having no capacity, and very loosely coupled to the secondary circuit.

For more detailed descriptions of various methods of measurement the reader (of German) is referred to "Die Frequenzmesser," &c., by Dr E. Nesper (Von Veit, Leipzig, 1907), and to Dr Zenneck's "Elektromagnetische Schwingungen" (Enke, Stuttgart, 1905).

Measurement of Coupling.—(1) *By Damped Oscillations.*—The degree of coupling κ (see page 259) is usually given as a percentage, *e.g.*, $\kappa=0.1$ is stated as 10 per cent., since $\kappa=1$ is the maximum theoretically possible. In practice 60 per cent. is about the maximum, and anything over 10 per cent. is called close coupling.

A determination of the degree of coupling may be made by letting a damped oscillation in the primary react upon the secondary circuit. The method is to take a resonance curve by a wavemeter with a hot-wire instrument in circuit, measuring as usual the current for different values of the frequency or wave-length as shown on the meter. A double peaked curve, like those of Fig. 149, will be obtained in which N′ and N″ are the frequencies corresponding to the peaks. Having obtained N′ and N″ thus, the degree of coupling κ may be calculated from the formula,

$$\kappa=(N'^2-N''^2)/(N'^2+N''^2), \text{ or from } \kappa=(\lambda''^2-\lambda'^2)/(\lambda''^2+\lambda'^2).$$

(2) *By Uniform Alternate Current.*—If a source of uniform high frequency current is available, such as a Poulsen arc or high frequency alternator, the mutual inductance of two circuits may be found from the formula, $M=\gamma_o''\frac{L_2\delta_2}{\pi\gamma_o'}$, where L_2 is high frequency inductance, and δ_2 decrement per whole period of the secondary, and γ_o' and γ_o'' are amplitudes of the uniform currents in primary and secondary. If the current has a sine wave form, γ_o' and γ_o'' may be found from the R.M.S., or hot-wire instrument reading, by multiplying by $\sqrt{2}$, *i.e.*, by 1.414. Hence, if L_1 is known, $k=M/\sqrt{L_1L_2}$, and also κ may be calculated.

Antenna Resistance.—The total antenna resistance is obtainable by any of the methods described in Chapter XIV.

Radiation Coefficient.—The radiation coefficient or "radiation resistance" is obtainable by the author's method described in Chapter XIX.

CHAPTER XIX.

THE TELEGRAPHIC EFFICIENCY OF WIRELESS MEANS OF COMMUNICATION.

In considering the efficiency of wireless transmission it is necessary to distinguish between the telegraphic efficiency of transmission of signals, the efficiency of transmission of energy, and the operative efficiency. These are not synonymous, for the first includes, besides mere energy efficiencies, such factors as speed of signalling, and, if a telephone receiver be used, the suitability of the sounds produced to the hearing of the operator.

Table I. gives an indication of the chief quantities involved in an estimate of the efficiency of a wireless line of communication.

I shall commence my analysis by stating the general case, and shall then elaborate the details of the particular efficiencies concerned.

There is to be considered :—

The efficiency of the combination formed by a transmitting station P *and a receiving station* Q, *between which intervenes a given stretch of land or sea, as a means of transmitting verbal messages from* P *to* Q.

This includes, among other things, the efficiency of the combination as a means of transmitting energy from P to Q. I shall commence with this energy efficiency, as it is somewhat simpler to deal with than the others, since it contains only quantities which can be measured by physical methods and excludes such factors as speed of signalling and character of signals, which are commercial and psychological rather than physical.

TABLE I.—FACTORS IN THE EFFICIENCY OF A WIRELESS TELEGRAPH SYSTEM.

- Commercial Efficiency
  - Costs
    - Capital.
    - Running.
    - Salaries.
    - Administration, &c.
    - Depreciation.
  - Speed Value.
  - Telegraphic Efficiency
    - Operative
      - Reliability
        - Regularity
          - Design.
          - Construction.
          - Power.
        - Selectivity
          - Electrical Tuning.
          - Electrical Filtering.
          - Acoustic Tuning.
      - Speed
    - Energy
      - Territorial
        - Air
        - Earth
        - Sea
      - Instrumental
        - Transmitter
          - Supply
          - H.F. Generator
            - Conductors;
            - Capacities.
          - Coupling
          - Aerial—Earth Circuit
            - Metallic Conductors.
            - Earth Resistance.
            - Brushing.
            - Leakage.
            - Stays.
        - Receiver
          - Aerial—Earth.
          - Coupling (1).
          - Intermediate.
          - Coupling (2).
          - Detector.
          - Telephone or Recorder.

I shall also exclude for the present the important case of a central station transmitting simultaneously to a large number of separate receiving stations.

It is obviously incorrect to take the usual engineering definition of efficiency, *i.e.*, the ratio of the energy delivered by the receiver to the total energy supplied to the transmitter, as a measure of the efficiency of a pair of corresponding stations. With such a definition the maximum possible efficiency is always an absurdly small fraction on account of the divergence of the transmitted current over the earth's surface, even if the apparatus be perfect. Perfect efficiency represented by an infinitesimal fraction is absurd.

Definition of the Energy Efficiency of a Pair of Corresponding Wireless Stations.—I therefore propose that the fundamental basis of the measure of energy efficiency of a pair of stations shall be the ratio of the energy which is delivered by the receiver at the final stage, to the energy which would be delivered if there were no dissipation as heat on the way,—the supply to the transmitter being the same in both cases.

This measure is analogous to the theoretical efficiency of a heat engine. In a perfectly reversible heat engine only a certain proportion of the heat supplied is convertible into work, and this proportion depends on the difference of temperature between the boiler and the condenser and on the absolute temperature. The theoretical efficiency can only reach unity if the condenser be at absolute zero of temperature, which is, of course, an unrealisable condition. Thus the theoretical efficiency is always less than unity. The efficiency of a real engine is measured by the ratio of two fractions, *i.e.*, by the ratio of the actual power to the power which would be given by a theoretically perfect engine working between the same temperatures.

In considering a pair of wireless stations we have to take into account that the absorption of all the energy radiated is as impossible as the attainment of absolute zero of temperature, for the receiving aerial can, at best, abstract from the ether only a small fraction of the total energy radiated, since its linear dimensions are limited by many considerations, however perfect may be its construction otherwise. It is clear, therefore, that the definition proposed, by taking as a standard the power delivered by the receiver on the assumption of no waste of energy in transmission, or in the various conversions in the apparatus, gives a theoretical highest possible efficiency which resembles the theoretical efficiency of a heat engine.

This definition thus eliminates reduction of energy density by divergence of the radiation, leaving only the true joulean waste of energy as source of inefficiency.

Directive Transmission.—The definition does not, so far, take account of non-symmetrical radiation from the aerial. It would be necessary, therefore, if unsymmetrical aerials were used, to place them so that the directions of maximum radiation and maximum absorption of the receiver were in the line joining the stations. The laws of distribution of radiation from existing forms of aerial are well known, thanks to the experiments and theoretical work of Marconi,* Braun,† Bellini and Tosi,‡ and others, and are determinable by experiment or calculation for any new form. It seems right, therefore, that the primary definition of the efficiency should include this factor, for if it did not we might have a pair of similar directive stations, each of whose individual energy efficiencies, considered as radiator and absorber, were nearly perfect, giving a low combined efficiency; while the efficiency of a pair consisting of one of these stations and of a third of the same type but in some other direction, might be high,—a result which appears to me to lead to a less useful numeric, since the efficiency would then depend largely on orientation and not wholly on construction.

As, therefore, it is desirable to include the case of directive aerials we may do so presuming that the law of distribution of radiation of each aerial is known.

Suppose, for instance, that the ratio of the actual radiation, in a direction making a horizontal angle θ with the direction of maximum radiation, to the radiation from a symmetrical aerial having the same total efficiency and the same supply of power, is $=f(\theta)$, which we may call the directive function, then the actual efficiency of any pair of stations may be expressed as—

$$E = f_1(\theta_1) \cdot f_2(\theta_2) \cdot e,$$

where θ_1 is the angle between the line joining the stations and the direction of maximum radiation of the transmitter, θ_2 the angle between the same line and the direction of maximum absorption of the receiver, and e the efficiency of a pair of stations having vertical aerials but similar in every other respect to the directive stations, and hence having the same total radiation efficiency.

E will be a maximum when $\theta_1 = o$ and $\theta_2 = \pi$. This indicates the possible advantage of using a directive aerial instead of a symmetrical one with equal supplies of energy. If the total radiation efficiencies are equal, the actual radiation from the directive aerial will be greater than that of the symmetrical one in some directions and less in others. As a matter of fact it is practically certain that the loss of energy through the induction of currents in the ground below the horizontal part of a directive aerial usually renders the total efficiency of the directive aerial less than that of a good symmetrical one. Hence the advantage of using the directive form is somewhat reduced in practice.

Re-stating the definition in the form to which it has now been brought we have:—

---

* *Proc. Roy. Soc.*, 22nd March 1906.

† *Jahrbuch der drahtlosen Telegraphie*, 1, 1, 1907.

‡ *Phil. Mag.*, Series 6, vol. 16, p. 638, 1908; also *Proc. Phys. Soc.*, vol. 21, p. 305, 1909.

The energy efficiency of a pair of wireless stations for a given supply of power to the transmitter is the ratio of the power delivered by the receiver at its final stage to the power which would be delivered if there were no waste of electric energy by conversion into heat;—multiplied by the directive functions of the aerials.

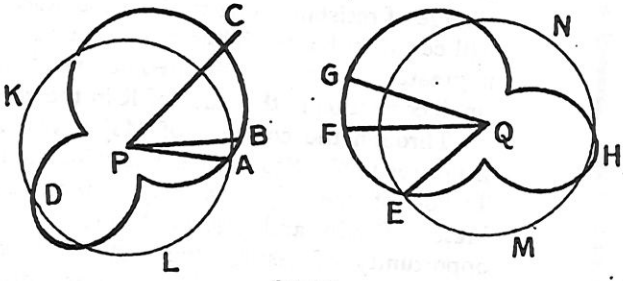


FIG. 197.

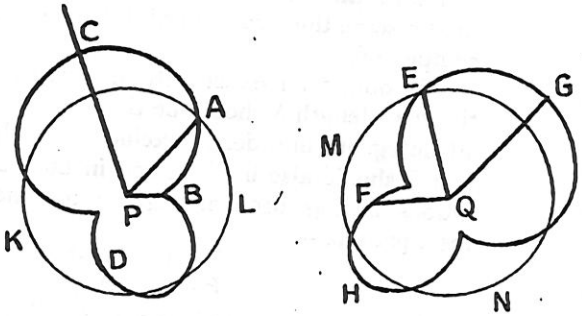


FIG. 198.

To put this definition into symbols in order to illustrate it: let the curves ABCD, EFGH (Fig. 197) represent the radiation distribution curves of the station P and Q. Let the circles AKL and EMN represent the radiation distributions round the same, or exactly equivalent, stations using symmetrical aerials and having an equal power supply. Then $PA=r_0$ represents the radiation from the equivalent symmetrical aerial, $PB=r$ represents the actual radiation in the direction of Q, and $PC=r_m$ represents the maximum possible density of radiation from the station P.

$QE=r'$, $QF=r'$, and $QG=r'_m$, represent powers of absorption at the receiving station. It may be assumed that in this case these are proportional to the powers of radiation of the aerial at Q, although in general there is no necessary proportionality between powers of radiation and power of absorption. The question is easily tested by experiment. The angle $CPB=\theta_1$, and $GQF=\theta_2$.

We have, therefore, $r/r=f_1(\theta_1)$, and $r'/r'_0=f_2(\theta_2)$. Hence—

$$E=\frac{r}{r_0}\cdot\frac{r'}{r'_0}\cdot e.$$

For Fig. 197 we have $E>e$, and for Fig. 198 $E<e$.

A Direct Experimental Method for the Determination of the Radiation Efficiency, Earth Resistance and other Constants of a Transmitter.—I have worked out the following method* of obtaining a direct measurement of the power radiated and also of the power wasted owing to resistance in the antenna and in the earth in its immediate neighbourhood. From the former it is at once possible to calculate the efficiency of the station as a radiator, since this efficiency is simply the ratio of power radiated to power supplied. The method thus renders possible a measurement of fundamental importance in radiotelegraphy which it has not hitherto been possible to make.

The method of measurement is as follows:—

(*a*) Erect a small antenna at several wave-lengths distance from the station, the efficiency of which is to be measured. In series with this antenna place a hot-wire current measuring instrument and connect to earth. The resistance of this instrument should preferably be so high that free oscillations are not possible (*i.e.*, $R^2C>4L$), although this condition does not appear to be necessary if precautions are taken to tune the test antenna to the frequency of the station.

---

* *Jahrbuch der drahtlosen Telegraphie*, Bd. 5, Hft. 5, 1912.

(*b*) Measure the current i_1 induced in the test antenna by the waves from the station and the current I_1 in the station antenna. Then i_1^2 is very approximately proportional to the power taken from the waves, and hence to the energy density of the radiation at the test antenna, and therefore to the total power radiated from the station. Also, if R be the unknown ohmic resistance representing all joulean losses in antenna and earth at the station, I_1^2R is the power wasted by conversion into heat at the station.

(*c*) Next alter the height of the station antenna (without changing the length of the conductors), so that its total radiation is slightly altered, *e.g.*, by lowering it make the radiation somewhat less. Experiments show that a difference of about 10 per cent. in the height is sufficient. Again measure the currents in the antennas: let these be i_2 and I_2.

In (*b*) and (*c*) it is necessary that the low frequency power supply should be measured. It should be adjusted to approximately the same value in both cases.

It is also advantageous that P, the high frequency power supply to the antenna, should be constant. This can be ensured by making the low frequency power and the current in the primary high frequency circuit both constant, altering the coupling, if necessary, between primary and antenna. It is not necessary, however, that P should be constant, only if it is not so two measurements of the power in the antenna will be necessary.

It is necessary that the wave-length λ should be the same in both measurements. Luckily for the simplicity of the method this condition is one which causes no difficulty, for I find that for a difference of say 10 per cent. in height of the antenna, obtained by lowering it without changing the length of the conductors, the wave-length does not vary appreciably. This convenient circumstance is no doubt due to the fact that this change of the height of the antenna, while increasing its capacity, decreases its inductance. The natural frequency of oscillation, therefore, remains very approximately the same. If on more exact measurement it is found that there is an appreciable change of wave-length, a small adjustment of the antenna tuning inductance will be necessary. The change of resistance due to this small additional inductance will certainly be negligible to a first approximation, while if greater accuracy is required it may be allowed for by a small correction to the value of R in the equations (1) below.

Through the courtesy of Major W. E. O'Meara, Chief Engineer to the Post Office, and with the help of Mr J. E. Taylor of the Wireless Department, and his assistants Messrs Perrin and Rivers Moore, I had an excellent opportunity of testing the method in practice recently. As, however, the experiments were merely preliminary and time did not permit of a complete determination, I shall reserve the results until I am able to give them in a complete form.

To obtain an exact determination it is necessary that the wave-length λ should be the same in both cases. It is advantageous in order to exclude possible sources of error that P should also be the same in both cases. These conditions having been arranged experimentally we obtain the equations—

$$\left.\begin{aligned} P &= Ai_1^2 + RI_1^2 \\ P &= Ai_2^2 + RI_2^2 \end{aligned}\right\} \quad - \quad - \quad - \quad (1)$$

In these two equations we have five known quantities, P, i_1, i_2, I_1, and I_2, and two unknowns, A and R. The quantities A and R are, therefore, determined by the solution of the equations. The only assumption is that the values of A and R are constant for the small variation of the height of the antenna which has been made. That this is the case, to a first approximation at least, may be shown in the following manner.

As regards R, we see that the constancy of the wave-length λ ensures that the area of ground under the antenna and in its neighbourhood which is included in the antenna-earth circuit is constant, since the diameter of this area depends on the wave-length. For the same reason the depth of penetration into the ground is constant. Any variation of the value of R which may occur is therefore due only to the small difference of distribution of current in this fixed area and is of the second order of small quantities, and is therefore negligible to a first approximation. Also, since R is kept constant, the other factors of R, such as brush discharges, leakage, and dielectric hysteresis, do not vary appreciably. To a first approximation, therefore, R is constant (see also note, below).

As regards A, the fact that λ is constant ensures that the test antenna is at the same number of wave-lengths from the station in both measurements. Also, since the type of antenna is not altered by slightly changing the height, it is clear that the horizontal distribution of radiation is not appreciably different in the two cases, and hence the orientation of the test antenna is the same as regards horizontal distribution of radiation. Thus, since the test antenna is at the same number of wave-lengths distant and in the same part of the field of radiation, the only electrical difference is in the density of energy in its neighbourhood. This change of energy density is fully represented, in the term Ai^2, by the change from i_1^2 to i_2^2. Hence A is a constant for the conditions of experiment in which the equations have been obtained.*

---

* In a letter in the *Jahrbuch*, Bd. 5, H. 5, from my friend Dr J. Zenneck, the constancy of A and R is confirmed by working out a special case.

Dr Zenneck also points out that if the measurements be taken with four different heights of antenna instead of with only two, equations are obtained from which it is possible to calculate dR/dh and dA/dh, thus giving results accurate to a second approximation at least.

I am of opinion that the results of the first approximations are sufficiently accurate for all practical purposes, but it is useful to know that the method may easily be extended to give as great a degree of accuracy as is desired for any specific purpose.

It is clear, therefore, that the equations

$$\left.\begin{aligned} P &= RI_1^2 + Ai_1^2 \\ P &= RI_2^2 + Ai_2^2 \end{aligned}\right\} \quad - \quad - \quad - \quad (1)$$

may be solved for A and R in the ordinary manner.

If P is the same for both heights of aerial the solutions are

$$R = P\frac{i_2^2 - i_1^2}{I_1^2 i_2^2 - I_2^2 i_1^2} \quad - \quad - \quad - \quad (2)$$

and

$$A = P\frac{I_1^2 - I_2^2}{I_1^2 i_2^2 - I_2^2 i_1^2} \quad - \quad - \quad - \quad (3)$$

where R is the ohmic resistance representing all joulean losses in the antenna-earth circuit, and A is the constant by which i_1^2, the square of the test antenna current, must be multiplied to obtain the total power radiated. If P_1 for the full height of the aerial is not equal to P_2 when aerial lowered, their values must be put in equations (1) and the solutions modified accordingly.

In order to reduce these solutions to actual numbers it is necessary to know the high frequency power P supplied to the antenna by the primary high frequency circuit.

This may be determined by a calorimetric method or by a method involving electrical measurements only.

For the calorimetric method a circuit must be made up to represent the antenna-earth circuit as nearly as possible. It is not satisfactory to use an aperiodic circuit to absorb the energy and convert it into heat, as its reaction on the primary is different from that of a resonating circuit. An air condenser of approximately the capacity of the antenna and an inductance to give the proper wave-length should be used in series with a resistance,—the latter being immersed in the calorimeter.

The value for the resistance should be roughly approximate to the total of the ohmic and radiation resistances of the antenna. This approximate value may be obtained by the process known as "trial and error" by assuming a probable value for P and then calculating the value of R and r from the equations given in this paper. Their sum is a resistance suitable for use in the calorimeter.

P may now be determined by the well-known method of measuring the rate of heat production in the calorimeter and reducing the heat units to electric power. If the value of P so determined be much different from that assumed previously, the determination should be carried out again, using a heating resistance calculated by using the new value of P, when a still more accurate value of P will be obtained.

It is clear, therefore, that the high frequency power P given to the antenna by the primary H.F. circuit may be determined to any required degree of accuracy.

There is another method for the determination of P which, although possibly not so satisfactory as the calorimetric method, is more easily carried out. This may be given as follows:—

$$P=(R+r)I_1^2,$$

where R is ohmic resistance, as above, and r is the "radiation resistance" of the antenna. But—

$$\delta=\frac{R+r}{2nL},$$

hence

$$R+r=2nL\delta,$$

and therefore

$$P=2nL\delta I_1^2 \quad - \quad - \quad - \quad - \quad (4)$$

where n = frequency, δ = log decrement, and L = total inductance in the antenna-earth circuit. These may all be determined without difficulty:—n by the wavemeter, δ from a resonance curve, and L as follows (or otherwise):—

Take two readings of the wave-length of the free oscillation of the antenna, using different inductances in series with the antenna. Let the extra inductances be L_1 and L_2 while the unknown inductance of the external antenna circuit is L_a. Let the wave-lengths be λ_1 and λ_2.

Then by substitution of these values in the equation

$$\lambda=k\sqrt{CL}$$

and solution of the two resulting equations, we get

$$L_a=\frac{L_2\lambda_1^2-L_1\lambda_2^2}{\lambda_1^2-\lambda_2^2} \quad - \quad - \quad - \quad (5)$$

for the external antenna inductance, and hence $L_a+L_1=L$, the total inductance in the antenna circuit, is known and may be inserted in the equation (4) for P given above.

We have, therefore, the following values for R and A in terms of known quantities experimentally determined—

$$R=P\cdot\frac{i_2^2-i_1^2}{I_1^2i_2^2-I_2^2i_1^2} \quad - \quad - \quad - \quad (6)$$

and

$$A=P\frac{I_1^2-I_2^2}{I_1^2i_2^2-I_2^2i_1^2} \quad - \quad - \quad - \quad (7)$$

The numerical value of the ohmic resistance representing all joulean losses in the antenna-earth circuit is given by the equation for R, and the factor by which the current (squared) in the test antenna must be multiplied to obtain the total radiated power is given by the equation for A.

As regards other important quantities we have, for the total power radiated,

$$p=Ai_1^2,$$

or by substitution,

$$p=Pi_1^2\frac{I_1^2-I_2^2}{I_1^2i_2^2-I_2^2i_1^2} \quad - \quad - \quad - \quad (8)$$

The efficiency of the antenna-earth circuit as a radiator is

$$E_a=p/P=Ai_1^2/P$$

or

$$E_a=i_1^2\frac{I_1^2-I_2^2}{I_1^2i_2^2-I_2^2i_1^2} \quad - \quad - \quad - \quad (9)$$

Also we have for the radiation resistance,

$$r=p/I_1^2=P\frac{i_1^2}{I_1^2}\cdot\frac{I_1^2-I_2^2}{I_1^2i_2^2-I_2^2i_1^2} \quad - \quad - \quad (10)$$

Finally, for the overall efficiency of the station as a transmitter of energy, we have—

$$E_o = E_a \frac{P}{P_o} = \frac{P}{P_o} \cdot i_1^2 \cdot \frac{I_1^2 - I_2^2}{I_1^2 i_2^2 - I_2^2 i_1^2} \quad \cdot \quad (11)$$

where P_o is the low frequency power supply.

Conclusion.—The whole problem of the efficiency, earth resistance, and radiation resistance of a wireless transmitter has thus been solved by a method, correct in theory and comparatively simple in practice, involving, in addition to such measurements of current and wave-length as are usual in every well-equipped wireless station, only a very simple calorimetric determination of power.

In practice the method is susceptible of any desired degree of accuracy (see note, p. 370). Its chief uses to the engineer are (1) the determination of the efficiency of a transmitting station; (2) the determination of the more important constants of an antenna-earth circuit—including its efficiency as oscillator and radiator, its ohmic resistance and its radiation resistance; (3) the selection of sites for permanent stations by comparative measurements of earth resistance with portable apparatus. From the investigator's point of view it provides a means of measuring the radiation resistances of various types of antenna, of studying the resistance of various kinds of soil, and of investigating the practical effects of ground water at different depths, thus confirming and extending the excellent theoretical work which has already been done on these subjects.

Operative Efficiencies.—We have now to consider the *operative* as distinguished from the *energy* efficiencies. These are less definite in character, not being usually expressible in terms of physical units, but they are of so great importance that an attempt to analyse, define, and co-ordinate them cannot but be of practical value. So far as I am aware no such attempt has hitherto been made. I wish, therefore, to say that I consider the definitions which I give below as more or less tentative in form, and that some modification may be necessary after more complete discussion.

It is obvious that the energy efficiency of the station is by no means the only important factor in its telegraphic efficiency, and that there are many other conditions which must be fulfilled in order that the station may be an efficient link in a system of communication. Among these factors the more important variables are, for instance, the type of current transmitted and the method by which its presence is made audible or visible in the receiving station. Thus a perfectly uniform H.F. current cannot be detected by means of a telephone in an ordinary continuously-acting detector circuit, even though the energy is comparatively large, while in the same circuit an intermittent current would produce audible signals even if it were of small energy. Conversely, if there be an interrupter in the detector circuit, a uniform H.F. current becomes audible, and an intermittent one practically inaudible, unless the spark frequency is high. The proper combination of transmitter and receiver is, therefore, essential to telegraphic efficiency. Telegraphic efficiency also includes physiological phenomena which are at present beyond the range of physical measurement.

Reliability.—The term "*reliability*" in telegraphic working is practically synonymous with "*uniformity*." The reliability of a system of communication is not dependent on its energy efficiency unless the power supply is limited. Reliability implies simply that good readable signals can always be obtained between the stations without any variation of the adjustments of the apparatus, on every occasion when communication is desired. High energy efficiencies are not essential to reliability: it is sufficient that signals should come through somehow with unvarying strength and distinctness. To attain this most desirable end it may be necessary to sacrifice, to some extent, electrical efficiency in favour of substantiality of mechanical construction in the instruments; it may also be necessary to avoid very sharp tuning. The reliability of a pair of stations may thus be defined as the ratio. (*Time which should be spent in transmission of a day's traffic at the usual rate of sending.*)/(*Time actually spent in transmission of the same days' traffic, including delays due to instrumental and other causes.*)

For high reliability an ample reserve of power is required in order that signals may not be weakened too much by atmospheric and other disturbances. Means for high-speed transmission and reception are also useful, since, on the average, the number of atmospheric disturbances per word is inversely as the speed of transmission. Appliances for ensuring freedom from interference are useful, except in so far as they introduce complications tending to greater uncertainty in operation. Good mechanical and electrical design and construction of the instruments are also important factors.

Speed of Transmission.—High speeds of transmission are valuable in the following conditions: (1) Where the cost of the apparatus is a large proportion of the total costs; (2) where a second station would interfere with the working of the first; (3) where "atmospherics" are frequent but not continuous.

Speed of transmission is usually reckoned in words per minute, each word being the same length as five V's in the Morse code, *i.e.*, equivalent to fifty dots.

Tuning.—Under operative efficiencies we must also include the capabilities of the apparatus as regards tuning or syntonisation. Two distinct quantities have to be considered in regard to tuning. These are: (1) *Exactness of tuning, and* (2) *sharpness of tuning.* The first is merely a question of the fineness of the adjustments of the instruments, the second is an essential physical property of the apparatus employed. It may be noted that unless means for exact tuning are provided it is quite possible to miss the signals altogether. Arrangements for giving a slow variation of the natural wave-length of the receiver are thus essential, especially where the received waves are only very slightly damped.

Sharpness of tuning may increase operative efficiency by decreasing the risk of interference by other stations, but it may decrease efficiency if the tuning is so sharp as to make it difficult to pick up, and tune correctly to, the received signals.

Acoustic Tuning.—In addition to the equalisation of the electrical frequencies it is now possible to introduce another safeguard against interference by causing the wave trains to be emitted in groups at an audible frequency. Sending stations can thus be distinguished from one another, although tuned to the same electrical frequency, by the use of an acoustical resonator (monotone telephone), or simply by the pitch and character of the note heard by the operator.

If the station be worked by continuous, or nearly continuous, waves, an *interrupter* in the receiving circuit, while assisting in reception, has the additional advantage of cutting out to a considerable extent stray signals which may come from stations of low spark rate; for in order that a dot may be audible it is essential that the receiving interrupter should be closed during its reception, and the chances against this are very large if the interrupter only closes the circuit for short periods with comparatively long blank intervals between.

The Telegraphic Efficiency.—All the quantities described in the preceding sections are factors in the telegraphic efficiency of the wireless system. To attempt to combine them in one formula appears to me to be rather premature at present. I have, however, indicated the nature of the connections between them in the tabular statement of Table I., page 362.

CHAPTER XX.

ON THE CALCULATION OF A SYNTONIC WIRELESS TELEGRAPH STATION.

THIS chapter is almost entirely a translation Signor Alfredo Montel has very kindly permitted me to make of a paper contributed by him to *L'Elettricista* of 15th June 1906, and gives a concise description of the calculations involved in the design of a wireless telegraph station. The methods and results are, of course, only roughly approximate, as exact data and theory are still wanting. The approximation, however, gives an excellent idea of the magnitude of the quantities involved, and of the proper dimensions of the apparatus in any given case. I have added a few short explanations where they seemed necessary, but have otherwise adhered closely to the original.

It should be noticed that, contrary to usual English custom, the frequency *n* represents the number of half periods per second. To reduce the equations in which it occurs to English notation, we should therefore have to write 2N in place of *n*, N being the number of *complete* periods per second. In the numerical examples it is simpler to make the calculations as they stand, recollecting that we should call the frequency one and a half and not three millions per second.

Without further prologue we commence Signor Montel's paper :—

"The transmitting station consists essentially (Fig. 199) of a closed oscillating circuit, and of an antenna coupled to

the same. C_1 is the condenser, B B a source of energy (*e.g.*, the secondary of a transformer), F F the spark-gap, L_1 the inductance of the circuit.

"In syntonic telegraphy large quantities of energy occur, hence if C_1 is to be of convenient size, while C_1L_1 does not exceed a certain limit (and also to economise energy), it is necessary to make L_1 small. The ohmic resistance should be small, and the gap F F should be subdivided into small parts. These conditions are chosen with a view to making the coefficient of damping as small as possible.

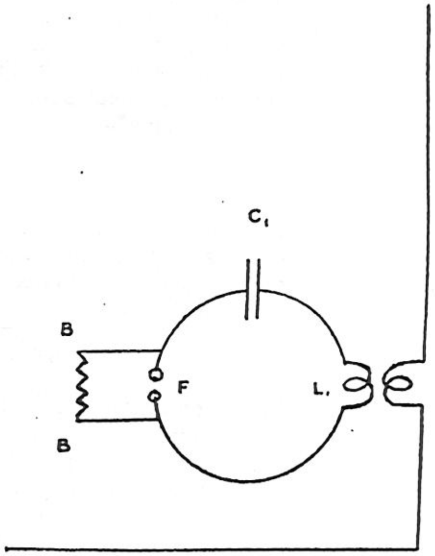


FIG. 199.

"The decrement (damping referred to the number of periods) depends mainly on the length of the spark, which may be from .4 to .5 cm. according to the capacity of the condenser, &c., and the resistance of the circuit. It depends also on the material and size of the spheres F F, and on the dielectric hysteresis of the condensers. Let a_1 be the decrement in the given oscillating circuit, and let us assume

$\alpha_1 = 0.06$, since this represents as small a decrement as we can expect in a circuit containing a spark-gap.

"In making the calculations for a circuit, one usually starts with the frequency n (the number of reversals per second), or what is equivalent, with the wave-length, which one intends to adopt for transmission. The wave-length should be greater in proportion to the distance, since waves of great length pass more easily round obstacles, and because greater amounts of energy necessitate greater wave-lengths. It does not do, however, to exaggerate the wave-length too much, since by so doing the sensibility to atmospheric disturbances is also increased.

"We have*—

$$n = \frac{1}{\pi\sqrt{C_1 L_1}} \quad - \quad - \quad - \quad - \quad (1)$$

L_1 is given by the form and dimensions of the circuit and the diameter of the wire. If, for example, the circuit is circular and of radius R, and the wire of radius r, we have the equation—

$$L_1 = 4\pi R\left[\log\frac{8R}{r} - 2\right], \text{ C.G.S.} \quad - \quad - \quad (2)$$

In this equation the internal inductance of the conductor is neglected since it is hardly appreciable with high frequencies and non-magnetic conductors.

"From (1) we obtain, by algebra—

$$C_1 = \frac{1}{\pi^2 n^2 L_1} \quad - \quad - \quad - \quad - \quad (3)$$

Let V_1 be the potential to which we require to charge the condenser on account of the distance to which we wish to telegraph, since the latter depends on the current in the aerial, and this again on its capacity and potential—

$$w = \frac{1}{2} C_1 V_1^2 \quad - \quad - \quad - \quad - \quad (4)$$

represents the quantity of energy consumed in one discharge, and if we take m as the number of these per second,

$$W = \frac{1}{2} m C_1 V_1^2 \quad - \quad - \quad - \quad - \quad (5)$$

represents the activity or horse-power of the station.

"The discharge must be oscillating, with as little damping as possible, *i.e.*, the resistance and radiation must be negligible. If, therefore, i_1 be the current of the discharge, then I_1, its maximum amplitude, is approximately for the case considered in which the damping is small,

$$I_1 = \frac{V_1}{\pi n L_1} \quad - \quad - \quad - \quad - \quad (6)$$

"*Numerical Example — Condenser Circuit of Transmitter.*—If the circuit be circular, the diameter of the wire 0.8 cm., the radius of the circuit 30 cm., and value of $n = 3 \cdot 10^6$, we get from (2) and (3)—

$$L_1 = 4 \cdot 3.14 \cdot 30\left[\log_e\left(\frac{240}{0.4}\right) - 2\right] = 1656 \text{ C.G.S.}$$

$$C_1 = \frac{1}{3.14^2 \cdot 3^2 \cdot 10^{12} \cdot 1656} = 6.8 \cdot 10^{-18} \text{ C.G.S.} = 6.8 \cdot 10^{-8} \text{ micro-}$$
farad.

"If we make $V_1 = 15{,}000$ volts $= 15 \cdot 10^{11}$ C.G.S., and $m = 30$, we get from (4) and (5)—

$$w = 0.5 \cdot 6.8 \cdot 10^{-18} \cdot 15^2 \cdot 10^{22} = 0.765 \cdot 10^7 \text{ C.G.S.} = 0.765 \text{ watt.}$$

$$W = 30 \cdot 0.765 = 22.95 \text{ watt.}$$

$$I_1 = \frac{15 \cdot 10^{11}}{3.14 \cdot 3 \cdot 10^6 \cdot 1656} = 96 \text{ C.G.S.} = 960 \text{ amperes.}$$

Now the aerial must have the same frequency n, considerable capacity, and great power of radiation.

"In place of using a direct earth connection, on account of its liability to variation (except in the case of an installation on board ship) it is better to employ an electrical counterpoise, *i.e.*, a conductor of considerable area, near the earth.

---

* See remark on frequency at commencement of chapter; also note that C and L are in C.G.S. electro-magnetic units (microfarad $= 10^{-15}$ and henry $= 10^9$ of these units).

"We shall assume for convenience in calculation that the aerial is a single wire, in which case *

$$n=\frac{3 \cdot 10^{10}}{2l} \quad - \quad - \quad - \quad - \quad (7)$$

l being the length of the antenna (aerial), on the supposition that the counterpoise is equal to the aerial given. From this equation we can get $l=5 \cdot 10^3$, if $n=3 \cdot 10^6$.

"For telegraphy to a given distance the magnitude of the current in the aerial practically fixes all the other conditions. The maximum potential on the aerial must not go beyond a certain limit, otherwise the charge would be dissipated by leakage; it also depends on the condenser circuit, and on the degree of coupling between the condenser circuit and the aerial. The relation between current and potential may be given as—

$$I_2=2nC_2V_2 \quad - \quad - \quad - \quad - \quad (8)$$

which we obtain from the known formula—

$$I=\pi nCV,$$

by taking account of the sinusoidal distribution of current and potential along the aerial. If we know V_2 and give a definite value to I_2, we obtain C_2. But also,

$$C_2=\frac{l}{2\log\frac{2l}{r}}\,\frac{1}{9}\,10^{-20}\text{ C.G.S.} \quad - \quad - \quad (9)$$

in which r is the radius of the aerial which we are seeking.

"In the case in which r is not negligible, as compared with the length of the aerial, the frequency n in place of the value given in (2) may be taken, according to M. Abraham, as

$$n=\frac{3 \cdot 10^{10}}{2l\left[1+5.6\left(\frac{1}{4\log\left(\frac{2l}{r}\right)}\right)^2\right]} \quad - \quad - \quad (10)$$

---

* According to Mr H. M. Macdonald the complete wave-length should be five times the length of the aerial, and not four times as here assumed. Experiments show that the intermediate number 4.8 is approximately the true value. (See Fleming, "Electric Wave Telegraphy," p. 559.)

But usually it is unnecessary to take account of the thickness of the aerial wire.

"Taking account only of the fundamental oscillation, we have, according to M. Abraham, the decrement a_2 of the aerial given by

$$a_2=\frac{2.44}{\log\frac{2l}{r}} \quad - \quad - \quad - \quad - \quad (11)$$

in which we neglect the damping due to heating on account of ohmic resistance. This is usually a correct assumption, as Sommerfeld has shown that the joulean heat waste produces a damping represented by the formula

$$a_J=\frac{1.1}{r}\sqrt{\frac{2\frac{\mu}{\mu_0}2l}{\sigma}} \cdot 10^{-7} \quad - \quad - \quad - \quad (12)$$

in which σ is the conductance in C.G.S., μ the permeability of the wire, μ_0 that of the dielectric medium, and r the radius of the aerial wire, and this quantity is small.

"The inductance of the aerial is, for high frequencies—

$$L_2=2 \cdot 2l \cdot \log\frac{2l}{r}\text{ C.G.S.} \quad - \quad - \quad (13)$$

"The coupling of the circuit of the condenser to the aerial should be as weak as possible, in order that the secondary may not react appreciably on the primary, and in order to have a maximum efficiency we must make sure that the current 'loop' is situated at the base of the aerial.

"Let M_{21} be the coefficient of mutual induction in the case of the given instantaneous value of the current at any point in the circuit. In our case we may put instead, the expression $\frac{4}{\pi}M_{21}$.

"The i_1 oscillating in the condenser circuit produces in the aerial an E.M.F. e_2, such that,

$$e_2=-\frac{4}{\pi}M_{21}\frac{di_1}{dt} \quad - \quad - \quad - \quad (14)$$

and if E_2 be its amplitude—

$$E_2=\pi n\left(\frac{4}{\pi}M_{21}\right)I_1=4nM_{21}I_1 \quad - \quad - \quad (15)$$

In the case of our aerial we may suppose that C represents the capacity which is given by the formula (9) for the aerial alone, that is to say, of the half of the internal system, we ought to take account of the sinusoidal distribution of the potential along it, and for this reason put instead $\frac{C}{\pi}$, and since L represents the inductance of the whole system which is given by (13), we must substitute for it $\frac{2L}{\pi}$. In equations (16) V represents the maximum difference of potential between the extremities of the circuit. Hence if we designate by V′ the maximum difference between the summit and base of the aerial, *i.e.*, between an extreme point and the middle of the oscillating circuit—

$$V' = \frac{1}{2}V \quad - \quad - \quad - \quad - \quad (17)$$

We therefore obtain from (16)—

$$\frac{1}{2}\frac{C}{\pi}(2V')^2 = \frac{1}{2}\frac{2L}{\pi}I^2.$$

From which

$$V' = I\sqrt{\frac{L}{2C}} \quad - \quad - \quad - \quad (18).$$

If, instead of the maximum values of the aerial voltage and current, we take the effective or virtual values ϕ, γ, we should get analogously

$$\phi = \gamma\sqrt{\frac{L}{2C}} \quad - \quad - \quad - \quad - \quad (19)$$

"The formula $n = \frac{1}{\pi\sqrt{(LC)}}$ in our case of a sinusoidal distribution of current and potential along the circuit reduces to

$$n = \frac{1}{\sqrt{(2LC)}} \quad - \quad - \quad - \quad - \quad (20)$$

And from (18), (19), (20), we obtain

$$I = \frac{V'}{nL} \quad - \quad - \quad - \quad - \quad (21)$$

$$\gamma = \frac{\phi}{nL} \quad - \quad - \quad - \quad - \quad (22)$$

"To return to the thread of our argument. The oscillating potential ϕ_2 of the aerial is the algebraic sum of the two v'_2 and v''_2, and if V'_2 be the common amplitude

$$\left.\begin{aligned} v'_2 &= V'_2 . e^{-a_1 t} . \cos\frac{\pi x}{2l}\sin(\pi n t - \psi') \quad - \quad - \\ v''_2 &= V'_2 . e^{-a_2 t} . \cos\frac{\pi x}{2l}\sin(\pi n t - \psi'') \quad - \quad - \\ \therefore\ \phi_2 &= v'_2 - v''_2 = V'_2(e^{-a_1 t} - e^{-a_2 t})\cos\frac{\pi x}{2l}\sin \pi n t \quad - \end{aligned}\right\} (23)$$

where x represents the distance from the top of the aerial.

"From theory * there results, in the case of our aerial, where V_2 is as in (8)—

$$V'_2 = \frac{1}{2}\frac{\pi E_2}{a_1 - a_2} \quad - \quad - \quad - \quad - \quad - \quad - \quad (24)$$

$$\left.\begin{aligned} V_{2\,\max} &= V_1\frac{M_{21}}{L_1} . \frac{2}{a_2}\left(\frac{a_1}{a_2}\right)^{\frac{a_1}{a_2 - a_1}} \quad - \quad - \quad - \quad - \\ &= \frac{1}{2}E_2\frac{\pi}{a_2}\left(\frac{a_1}{a_2}\right)^{\frac{a_1}{a_2 - a_1}} \quad - \quad - \quad - \quad - \end{aligned}\right\} (25)$$

$$\phi_2^2 = \frac{1}{8} . \frac{E_2^2\pi^2}{n} . \frac{1}{a_1 a_2(a_1 + a_2)} \quad - \quad - \quad - \quad - \quad (26)$$

E_2 is given by (15). From which three formulæ, and taking account of (21), we get the currents

$$I'_2 = \frac{\pi E_2}{2nL_2(a_1 - a_2)} \quad - \quad - \quad - \quad - \quad (27)$$

$$\left.\begin{aligned} I_{2\,\max} &= \frac{V_1 M_{21}}{nL_2L_1}\frac{2}{a_2}\left(\frac{a_1}{a_2}\right)^{\frac{a_1}{a_2 - a_1}} \quad - \quad - \quad - \\ &= \frac{1E_2\pi}{2nL_2a_2}\left(\frac{a_1}{a_2}\right)^{\frac{a_1}{a_2 - a_1}} \quad - \quad - \quad - \end{aligned}\right\} (28)$$

$$\gamma_2^2 = 1\frac{E_2^2\pi^2}{n^8L_2^2}\frac{1}{a_1 a_2(a_1 + a_2)} \quad - \quad - \quad - \quad (29)$$

"At the beginning of the jig I_2 and V_2 have the value zero, then, increasing gradually, they reach the maxima $I_{2\max}$ and $V_{2\max}$, and then commence to decrease.

---

* See J. Zenneck, "Elektromagnetische Schwingungen," p. 586.

"ϕ_2 and γ_2 are the effective values of the potential and current. The deflections of the measuring instrument are proportional to their squares.

"The equation (29) represents the effective value of the current during a single discharge, and γ_2 is proportional to a given quantity of energy per unit time. If in one second we have *m* discharges the quantity of energy per second would be *m* times as great, and hence we should have to put

$$\gamma_2^2 = \frac{m}{8} \frac{E_2^2 \pi^2}{n^3 L_2^2} \frac{1}{a_1 a_2 (a_1 + a_2)} \qquad - \quad - \quad (30)$$

and analogously—

$$\phi_2^2 = \frac{m}{8} \frac{E_2^2 \pi^2}{n} \frac{1}{a_1 a_2 (a_1 + a_2)} \qquad - \quad - \quad - \quad (31)$$

"*Numerical Example—Transmitting Aerial.*—Let us assume $M_{21} = 200$.

"From (13) we have, as we have shown, $L_2 = 160000$ C.G.S. and from (15)

$$E_2 = 4 \cdot 3 \cdot 10^6 \cdot 200 \cdot 96 = 2300 \cdot 10^8 \text{ C.G.S.} = 2300 \text{ volts.}$$

Substituting now in (24)......(28) we get

$$V'_2 = \frac{1}{2} \frac{3.14 \cdot 2300 \cdot 10^8}{0.3 - 0.06} = 15000 \cdot 10^8 \text{ C.G.S.} = 15000 \text{ volts.}$$

$$I'_2 = \frac{15 \cdot 10^{11}}{48 \cdot 10^{10}} = 2.88 \text{ C.G.S.} = 28.8 \text{ amperes.}$$

$$V_{2\,\max} = 15 \cdot 10^{11} \frac{200}{1656} \cdot \frac{2}{0.3} \left(\frac{0.06}{0.3}\right)^{\frac{0.06}{0.3 - 0.06}} = 8.30 \cdot 10^{11} \text{ C.G.S.}$$

$$= 8300 \text{ volts.}$$

$$I_{2\,\max} = \frac{8.30 \cdot 10^{11}}{3 \cdot 10^6 \cdot 16 \cdot 10^4} = 1.71 \text{ C.G.S.} = 17.1 \text{ amperes,}$$

and supposing that $m = 30$, we get from (31) and (22)

$$\phi_2^2 = \frac{30 \cdot 2300^2 \cdot 10^{16} \cdot 3.14^2}{8 \cdot 3 \cdot 10^6} \frac{1}{0.3 \cdot 0.06 (0.3 - 0.06)}$$

$$= 10050 \cdot 10^{16} \text{ C.G.S.}$$

Therefore

$$\phi_2 = 100 \cdot 10^8 \text{ C.G.S.} = 100 \text{ volts.}$$

$$\gamma_2 = \frac{100 \cdot 10^8}{3 \cdot 10^6 \cdot 16 \cdot 10^4} = 0.021 \text{ C.G.S.} = 0.21 \text{ amperes.}$$

"**The Receiving Circuit.**—Let us now pass to the consideration of the receiving station, which may be arranged as in Fig. 200. The aerial is supposed identical with the transmitting one, and is weakly coupled to an oscillating circuit, containing, for example, a coherer K and two condensers (the Marconi arrangement). The coherer at the first moment of arrival of the jig may be considered as a condenser. C_4 is a condenser of a capacity great compared with that of the coherer, connected in parallel with the coherer so that the general conditions of the circuit may not be affected by the variations of the capacity of the coherer caused by the movements of the

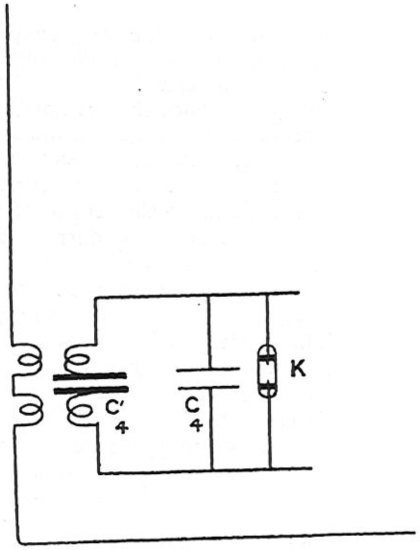


FIG. 200.

filings which it contains. C'_4 is a condenser which serves to prevent a short circuit of the relay and battery. Its capacity is much greater than that of C_4—so great, in fact, that the condition of the oscillating circuit whose ends are at C_4 and the coherer is not altered by its presence. In calculating the circuit approximately we shall not take the capacity of the coherer into account. We have

$$n=\frac{1}{\pi\sqrt{L_4C_4}}$$

in which n is the frequency adopted by the transmitting station. L_4 varies according to the shape and size of the circuit and the diameter of the wire. C_4 must be, as we said, great enough, but not too great, in order that we may not have to exaggerate the size of C'_4.

"According to the experiments of Duddell and Taylor and others, the effective current in the receiving aerial is proportional to the length of the aerial and to the strength of the transmitting current, and is inversely proportional to the distance between the stations.

"In our case let us suppose that by means of an instrument we know the current γ_3 at the base of the aerial. This current γ_3 is the resultant of a component i'_3 with the decrement α_1 of the transmitting station, and another i''_3 with the decrement α_2 of the receiving aerial. The equations for potential and current are analogous to (23).

"Knowing γ_3^2 we have from (30) by altering the suffixes

$$E_3^2=\frac{\gamma_3^2 8n^3L_2^2\alpha_1\alpha_2(\alpha_1+\alpha_2)}{m\pi^2} \quad - \quad - \quad (32)$$

Also—

$$V'_3=\tfrac{1}{2}\cdot\frac{\pi E_3}{\alpha_1-\alpha_2} \quad - \quad - \quad - \quad (33)$$

$$V_{3\,\max}=\tfrac{1}{2}E_3\frac{\pi}{\alpha_2}\left(\frac{\alpha_1}{\alpha_2}\right)^{\frac{\alpha_1}{(\alpha_2-\alpha_1)}} \quad - \quad - \quad - \quad (34)$$

$$I'_3=\frac{\pi E_3}{2nL_2(\alpha_1-\alpha_2)} \quad - \quad - \quad - \quad (35)$$

$$I_{3\,\max}=\frac{1}{2nL_2}E_3\frac{\pi}{\alpha_2}\left(\frac{\alpha_1}{\alpha_2}\right)^{\frac{\alpha_1}{(\alpha_2-\alpha_1)}} \quad - \quad - \quad (36)$$

$$\phi_3^2=\frac{m}{8}\cdot\frac{E_3^2\pi^2}{n}\cdot\frac{1}{\alpha_1\alpha_2(\alpha_1+\alpha_2)} \quad - \quad - \quad (37)$$

"*Numerical Example—Receiving Aerial.*—If at the base of the receiving aerial we find a current

$$\gamma_3=3\cdot 10^{-3}\text{ amp.}=3\cdot 10^{-4}\text{ C.G.S.}$$

Then from (37) we have—

$$\phi_3=3\cdot 10^{-4}\cdot 3\cdot 10^{6}\cdot 16\cdot 10^{4}=1.45\cdot 10^{8}\text{ C.G.S.}=1.45\text{ volt.}$$

"Applying results (32) to (36) we get—

$$E_3=\frac{3\cdot 10^{-4}\cdot 2\sqrt{2}\cdot 3\cdot\sqrt{3}\cdot 10^{9}\cdot 16\cdot 10^{4}}{\sqrt{30}\cdot 3.14}$$

$$=28.4\cdot 10^{8}\text{ C.G.S.}=28.4\text{ volts.}$$

$$V'_3=\frac{3.14}{2}\cdot\frac{28.4\cdot 10^{8}}{0.3-0.06}=185\cdot 10^{8}\text{ C.G.S.}=185\text{ volts.}$$

$$I'_3=\frac{185\cdot 10^{8}}{48\cdot 10^{10}}=3.8\cdot 10^{-3}\text{ C.G.S.}=0.38\text{ amp.}$$

$$V_{3\,\max}=\frac{1}{2}28.4\cdot 10^{8}\frac{3.14}{0.3}\left(\frac{0.06}{0.3}\right)^{\frac{0.06}{(0.3-0.06)}}=104\cdot 10^{8}\text{ C.G.S.}=104\text{ volts}$$

$$I_{3\,\max}=\frac{104\cdot 10^{8}}{48\cdot 10^{10}}=2.17\cdot 10^{-2}\text{ C.G.S.}=0.217\text{ ampere.}$$

"**The Secondary Circuit of the Receiving Station.**—The secondary of the receiving station consists essentially, as we have said, of the closed circuit of the condenser C_4. An E.M.F. e_4 is generated in it, at its point of coupling with the aerial, corresponding to the jigs transmitted by the sending station. Since this circuit is not interrupted by a spark-gap, it may be constructed so that its damping is exceedingly small; let us suppose it is $\alpha_4=0.006$.

"The jigs impressed on the circuit have the decrement $\alpha_1=0.06$ of the transmitting station, while in the receiving circuit itself the decrement is $\alpha_4=0.006$ as indicated above. At the commencement the resulting jig has obviously a zero value; it increases to a maximum and then decreases to zero again. Since α_1 is in our case much greater than α_4, the growth of the jig is much more rapid than its decline, hence we may assume, with an approximation which is good enough to give us at least the *maxima*, that we are dealing with an oscillation having a simple decrement a_4 and an amplitude equal to the maximum amplitude of the compound oscillation.

"The E.M.F. will be given by the formula—

$$e_4 = -M_{43}\frac{di_3}{dt} \quad - \quad - \quad - \quad - \quad (38)$$

And the amplitude of it is—

$$E_4 = I_{3\,\max}\,\pi n M_{43} \quad - \quad - \quad - \quad - \quad (39)$$

As we said before, at the beginning of the action of the jig, the coherer behaves as a condenser. While it does so our equations will hold, but when it reaches a maximum, or when the coherer is cohered (which may be sooner), they have served their purpose and are not afterwards valid. We may therefore assume that (24), (25), (27), (28) remain valid, as they only deal with the instantaneous values of current and potential at a point in the circuit; they may therefore be transformed into the following:—

$$V'_4 = \frac{\pi E_4}{a_1 - a_2} \quad - \quad - \quad - \quad - \quad (40)$$

$$V_{4\,\max} = E_4\frac{\pi}{a_4}\left(\frac{a_1}{a_4}\right)^{\frac{a_1}{(a_4-a_1)}} \quad - \quad - \quad - \quad (41)$$

$$I'_4 = \frac{E_4}{L_4 n(a_1 - a_4)} \quad - \quad - \quad - \quad (42)$$

$$I_{4\,\max} = E_4\frac{1}{nL_4a_4}\left(\frac{a_1}{a_4}\right)^{\frac{a_1}{(a_4-a_1)}} \quad - \quad - \quad (43)$$

"*Numerical Example—Coherer Circuit.*—From (40) (41), and (6) we have, putting $M = 200$ and $L_4 = L_1 = 1656$,

$$E_4 = 2.17 \,.\, 10^{-2} \,.\, 3.14 \,.\, 3 \,.\, 10^6 \,.\, 200 = 0.4 \text{ C.G.S.} = 0.4 \text{ volt.}$$

$$V'_4 = \frac{3.14 \,.\, 0.4 \,.\, 10^8}{0.06 - 0.006} = 23.6 \,.\, 10^8 \text{ C.G.S.} = 23.6 \text{ volts.}$$

$$V_{4\,\max} = 0.4 \,.\, 10^8 \,.\, \frac{3.14}{0.006}\left(\frac{0.06}{0.006}\right)^{-\frac{0.06}{0.054}} = 16.4 \,.\, 10^8 \text{ C.G.S.}$$

$$= 16.4 \text{ volts.}$$

$$I'_4 = \frac{23.6 \,.\, 10^8}{3 \,.\, 10^6 \,.\, 3.14 \,.\, 1656} = 0.15 \text{ C.G.S.} = 1.5 \text{ ampere.}$$

$$I_{4\,\max} = \frac{16.4 \,.\, 10^8}{3 \,.\, 10^6 \,.\, 3.14 \,.\, 1656} = 0.11 \text{ C.G.S.} = 1.1 \text{ ampere.}$$

"What we have given above may serve to give a quantitative idea, though only to the first order of approximation, of the phenomena of syntonic wireless telegraphy, and indicate the ways in which we may by calculation determine the dimensions of the various parts of an installation.

"The most notable result which arises from the numerical examples given is the demonstration of the difficulty of obtaining sufficiently high potentials for long-distance transmission.

"In general we may say the numbers resulting from the calculations are, if not always very close, at least sufficiently concordant to provide material for a study of the maxima and of the quantities dependent on them."

[*Note.*—The quantities on which the action of various types of detector depends are as follows:—

For coherers, $V_{4\,\max}$.

„ magnetic detectors, $I_{4\,\max}$.

„ thermo-galvanometers, γ^2.

J. E.-M.]

CHAPTER XXI.

TABLES AND NOTES.

In order to render the volume of greater service to those who are directly interested in wireless telegraphy, some numerical and diagrammatic Tables, with other useful matter, are given in this chapter. Several of the Tables are new, having been specially calculated for the purpose; in other cases the source from which the Table is taken is noted.

MORSE CODES.

	The European or Continental Code.		American Morse Code.
A	·—	A	·—
B	—···	B	—···
C	—·—·	C	·· ·
D	—··	D	—··
E	·	E	·
F	··—·	F	·—·
G	——·	G	— —·
H	····	H	····
I	··	I	··
J	·———	J	—·—·
K	—·—	K	—·—
L	·—··	L	———
M	——	M	——
N	—·	N	—·
O	———	O	· ·
P	·——·	P	·····
Q	——·—	Q	··—·
R	·—·	R	· ··
S	···	S	···
T	—	T	—
U	··—	U	··—
V	···—	V	···—
W	·——	W	·——
X	—··—	X	·—··
Y	—·——	Y	·· ··
Z	——··	Z	··· ·
	NUMERALS.		**NUMERALS.**
1	·————	1	·——·
2	··———	2	··—··
3	···——	3	···—·
4	····—	4	····—
5	·····	5	———
6	—····	6	······
7	—— ··	7	——··
8	———··	8	—····
9	————·	9	—··—
0	—————	0	—·——
.	·· ·· ··	.	··——··
?	··——··	?	—··—·
!	——··——	!	———·

TABLE I.—DIELECTRIC STRENGTHS OF VARIOUS INSULATORS.

Kilovolts per centimetre required to break down the Insulator.

MATERIAL.	
Micanite	4000
Mica	2000
American Linen Paper, Paraffined	540
Ebonite	538
Indiarubber	492
Linseed Oil	83
Cotton Seed Oil	67
Lubricating Oil	48
Air Film, 2 mm. thick	57
Air Film, 1.6 cm. thick	27

The numbers in this Table are taken from various sources.

NOTE.—For properties of Porcelain see H. F. Haworth, *Electrician*, 1st Jan. 1909.

TABLE II.—SPECIFIC INDUCTIVE CAPACITIES OR INDUCTIVITIES.

Inductivity of air taken as = 1.

Solids—		*Solids—*	
Ebonite	2.5	Paraffin wax	2.1
Glass, according to density	6.0 to 10.0	Sulphur	3.8 to 4.7
Guttapercha	3.0	*Liquids—*	
Indiarubber, pure	2.2	Castor oil	4.8
" vulcanised	2.8	Petroleum oil	2.1
Mica	6.7	Water at 15° C.	80

NOTE.—For high frequency currents the inductivity is usually somewhat less than the figure given.

TABLE III.—SPECIFIC RESISTANCES OF METALS.

Silver, 1,468; Copper, 1,561; Gold, 2,197; Aluminium, 2,665; Iron, 9,065; Tin, 13,048; Lead, 20,380; Mercury, 94,070. In C.G.S. units per cub. cm. (1 ohm = 10^9 C.G.S.).

Definitions and Formulæ.—*Frequency* = Number of complete cycles per second: Symbol N. *Period* = Duration of one cycle: Symbol T. *Wave-length*, in metres $= \frac{3 \times 10^8}{N}$: Symbol λ. *Natural Frequency* of an open electric circuit $= \frac{5 \times 10^6}{\sqrt{CL}}$, where C = Capacity in microfarads, L = Inductance in centimetres; or $\lambda \doteq 60 \sqrt{CL}$ metres. *Energy* in an oscillating circuit;—the potential energy of a charged condenser is $CV^2/2$ and the Kinetic Energy of a current is $LI^2/2$, where V and I are voltage and current.

Damping.—In a jig in which the oscillations are decreasing in amplitude the "damping" per period is the ratio of the amplitude of the second positive wave to the first. The Napierian logarithm of the *reciprocal* of this ratio is called the *logarithmic decrement* per period or cycle: Symbol δ. (See pages 240, 243, &c.)

In some English books the decrement is taken per half-period, *i.e.*, $\delta' = \log_e (a_1/a')$ where a_1 and a' are amplitudes of first positive and first negative waves. If a_2 be amplitude of second positive wave $\delta = \log_e(a_1/a_2) = \log_e\left(\frac{a_1}{a'} \cdot \frac{a'}{a_2}\right) = \log_e(a_1/a')^2 = 2\delta'$, since $a_1/a' = a'/a_2$. Hence $\delta = 2\delta'$.

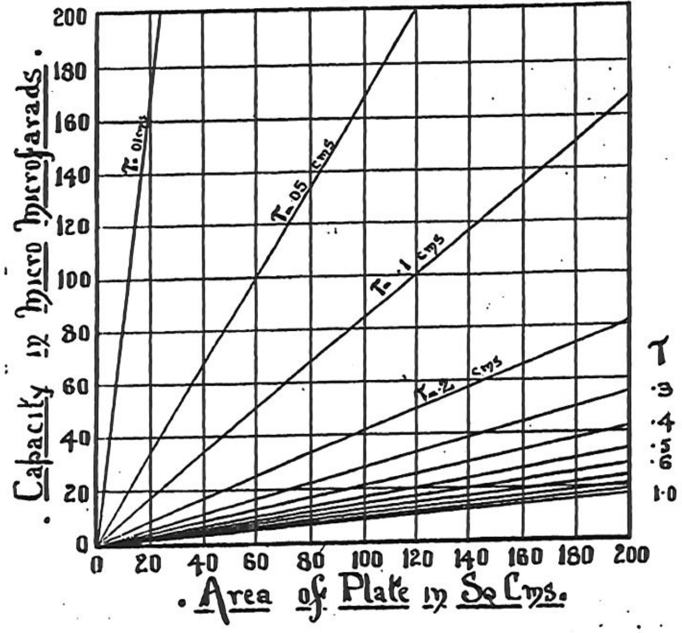
Burstyn's Units.—Dr W. Burstyn has suggested the following units as being of convenient magnitudes for calculations in radiotelegraphy:—

Unit of capacity = 10,000 cm.
Unit of inductance = 25,330 cm.

Then wave-length in kilometres, $\lambda = \sqrt{CL}$.

He has also proved that $\delta = \pi \cos \alpha$, where α is phase difference between voltage and current.

Table IV. Capacity of Parallel Plate Condenser.



The lines correspond to plates at distances T=.01 cm., &c. &c., apart. The values are only roughly approximate, unless the area be great in proportion to the thickness T of the dielectric.

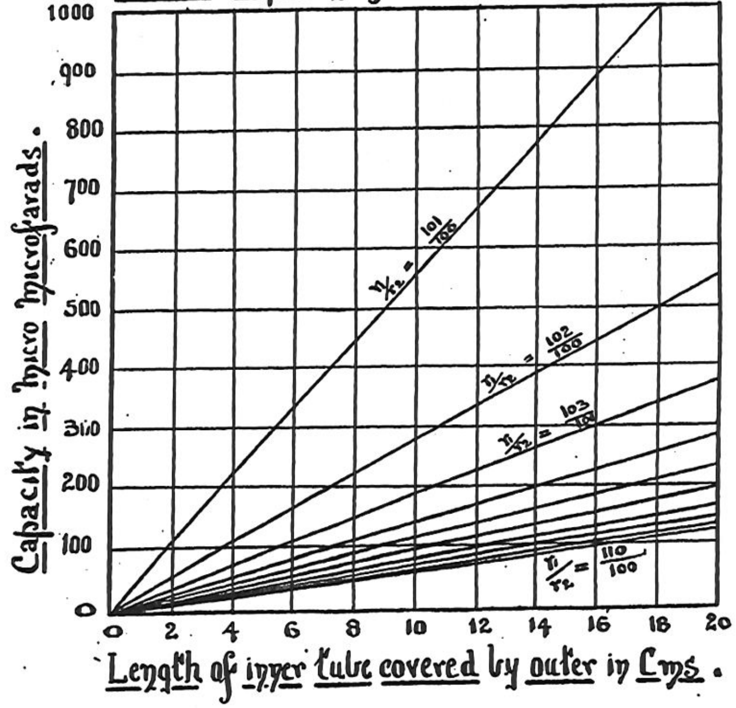
The dielectric is supposed to be air; if otherwise, multiply by inductivity.

To reduce to microfarads, divide by 10^6.

NOTE.—To find the capacity of a condenser larger or smaller than the range of the diagram, multiply both horizontal and vertical co-ordinates by the same factor throughout, *e.g.*, by 10 or $\frac{1}{10}$.

Example.—A pair of plates, each of 1,200 sq. cm. area, at 0.5 cm. apart in air have a capacity of 200 mmfd.

Table V. Capacity of a Cylindrical Condenser.



The dielectric is supposed to be air. Multiply by Spec. Ind. Capacity, if another dielectric is used.

The ratio r_1/r_2 is ratio of inside radius of outer conducting tube to outside radius of inner tube.

The lines between $r_1/r_2=103/100$ and $r_1/r_2=110/100$ are for values $r_1/r_2=104/100$, &c. &c. The absolute lengths of radii do not matter; only the ratio.

To obtain microfarads, divide by 10^6.

NOTE.—See Note to Table IV.

FORMULÆ FOR INDUCTANCES OF VARIOUS FORMS AT VERY HIGH FREQUENCIES.

In centimetres.

1 henry = 10^9 centimetres.

1. Straight wire, Length = l cms., Diameter = d cms.

$$L=2l(2.3026.\log_{10}\frac{4l}{d}-1).$$

2. Square circuit, Length of side = l cm., Diameter of wire = d.

$$L=8l(2.3026.\log_{10}\frac{16l}{d}-2.8).$$

3. Circular circuit, Diameter = D cm., Diameter of wire = d cm.

$$L=2\pi D\left\{\left(1+\frac{d^2}{4D^2}\right)(2.3026.\log_{10}\frac{4D}{d}-2)\right\}.$$

4. Long rectangle formed of two parallel wires and cross-piece at end, D cm. apart. Length of each = l cm., Diameter of wire = d.

$$L=4l\left(2.3026.\log_{10}\frac{2D}{d}\right).$$

5. Helix (one layer), N turns per cm., Diameter of Helix = D cm. Length of Helix = l cm.

$$L=(\pi DN)^2l\left[1-0.424\left(\frac{D}{l}\right)+0.125\left(\frac{D}{l}\right)^2-0.0156\left(\frac{D}{l}\right)^4\right].$$

NOTE.—Divide by 1000 to reduce to micro-henries.

Distributed Capacity in Coils.—F. A. Kloster (*Proc. Inst. Radio Engineers*, April 1913) gives results showing that any coil may be supposed to be replaced by a "true inductance" in parallel with a capacity, and gives experimental results and theory.

TABLE VIII.—RESISTANCE OF STRAIGHT COPPER WIRES TO CONSTANT AND TO HIGH FREQUENCY CURRENTS.

No. on S.W.G.	Diameter.		Resistance for Constant Current.	Resistance in Ohms per Metre for Uniform H.F. Currents of Frequencies		
				10^5.	10^6.	10^7.
	Inch.	Cm.	Ohms per Metre.			
12	.104	.264	.00312	.0109	.0328	.102
14	.080	.203	.00528	.0142	.0430	.130
16	.064	.163	.00824	.0180	.0527	.168
18	.048	.122	.0147	.0253	.0715	.223
20	.036	.091	.0260	.0358	.0933	.300
22	.028	.071	.0431	.0509	.1207	.389
30	.0124	.0315	.220	.220	.269	.900
32	.0108	.0274	.290	.290	.313	1.042
34	.0092	.0234	.398	.398	.416	1.235
36	.0076	.0193	.585	.585	.597	1.525
38	.0060	.0152	.943	.943	.950	2.080
40	.0048	.0122	1.466	1.466	1.473	2.580
42	.0040	.0102	2.109	2.109	2.200	3.260
44	.0032	.0081	3.300	3.300	3.300	4.070

Calculated from the formulæ of Kelvin, Maxwell, and Rayleigh as modified by Brylinski. If R be the C.C. resistance and R′ the H.F. resistance—

$$\frac{R'}{R}=1, \text{ when } \sqrt{a}=\sqrt{\frac{\mu\pi r^2p}{\rho}}<0.5.$$

$$\frac{R'}{R}=0.079\times4a-0.156\times2\sqrt{a}+1.077\text{ ; when }\sqrt{a}\text{ between .5 and 1.5.}$$

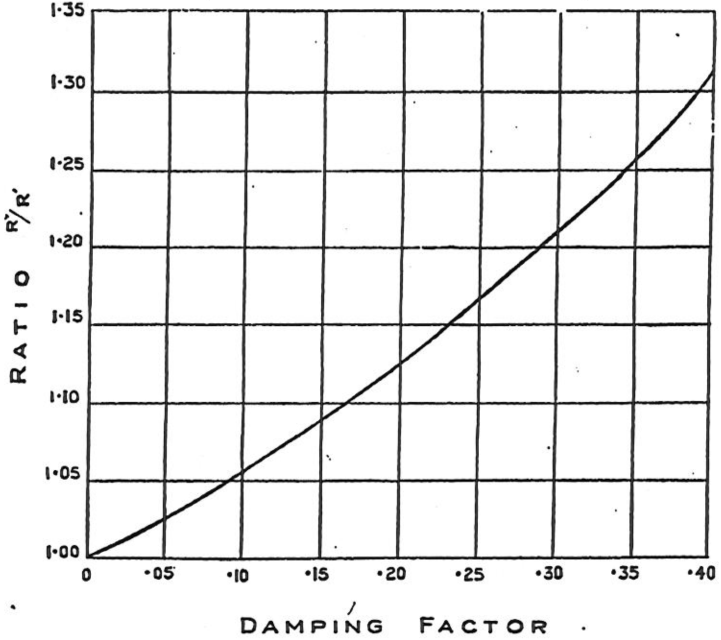
$$\frac{R'}{R}=\frac{2\sqrt{2a}+1}{4}\text{ ; when }\sqrt{a}>1.5.$$

NOTE.—The resistance of *bent* wires is somewhat higher owing to non-uniform distribution of the current.

NOTE.—*Aluminium Aerial Wire.*—A comparatively thick aluminium wire, say No. 16, of same diameter as a copper wire, has about 1.7 times the resistance, same capacity, and one-third of the weight per metre.

TABLE IX.—RATIO OF H.F. RESISTANCE R″ WITH DAMPING, TO R′, THE RESISTANCE GIVEN IN TABLE VIII. FOR UNIFORM H.F. CURRENTS.*

(From Dr E. H. Barton's formulæ.)



Damping factor = Logarithmic decrement per period divided by 2π.
D.F. = .05, therefore corresponds to $\delta = .314$; D.F. = .10 to $\delta = .628$.

Notes on Spark Resistance.

The resistance of the spark is in general the largest resistance in the path of the jig currents in wireless telegraph apparatus. It ranges from a fraction of an ohm for a spark length of about a millimetre up to 8 or 10 ohms for 1 cm., and its actual value depends on the materials of the electrodes, and also on the capacity in circuit and on the damping. The total resistance of a number of sparks in series is less than the resistance of a single spark whose length is the sum of the others; hence spark-gaps are now usually subdivided.

---

* *Phil. Mag.* May 1899, p. 433.

TABLE X.—SPARK LENGTHS IN AIR, WITH SPARK BALLS OF VARIOUS SIZES.

(From Mr E. Watson's Experiments, by kind permission of the Council of the Institute of Electrical Engineers.)

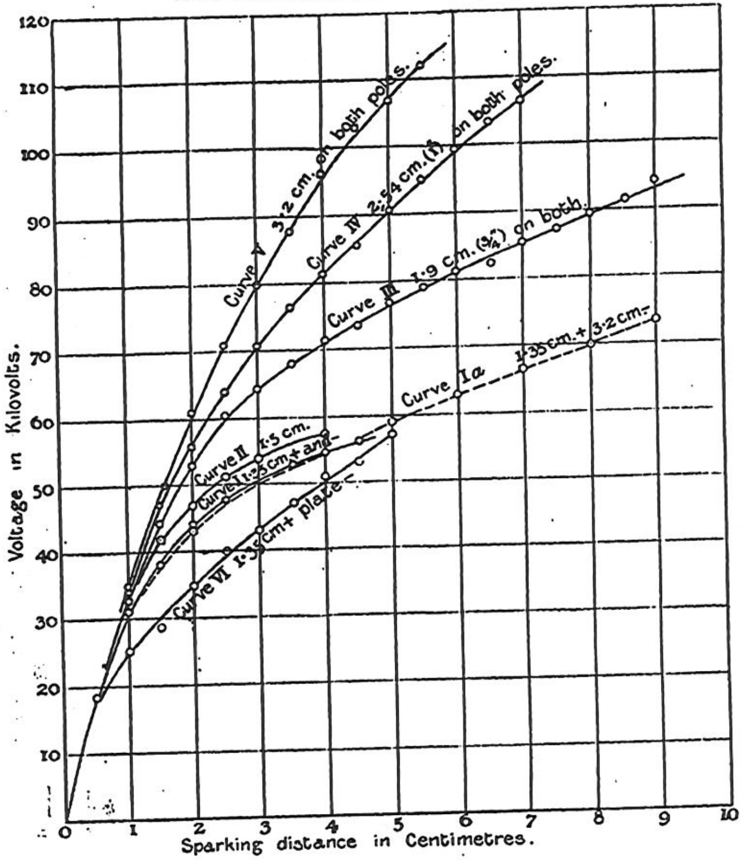
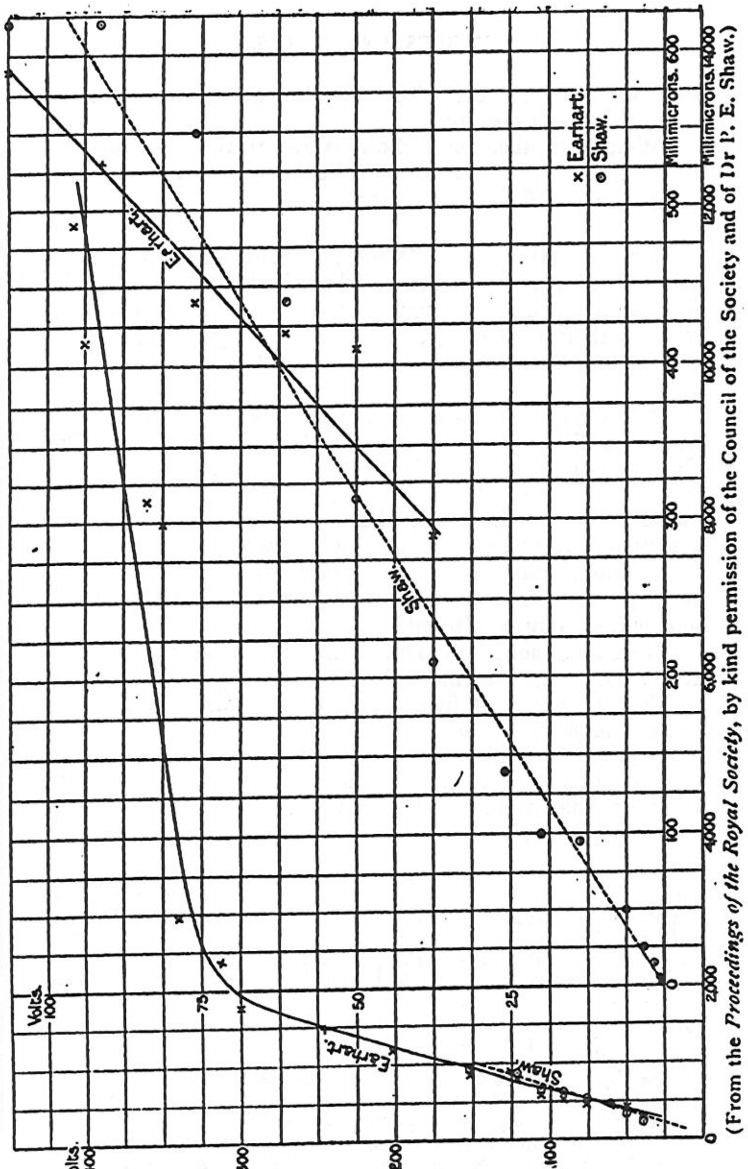


TABLE XI.—SMALL SPARKING DISTANCES IN AIR IN MILLIONTHS OF A MILLIMETRE.



(From the *Proceedings of the Royal Society*, by kind permission of the Council of the Society and of Dr P. E. Shaw.)

Calculation of Damping.—If δ_1 and δ_2 be the logarithmic decrements in the primary and secondary circuits, Brandes has shown that $\delta_1+\delta_2=K\frac{C_2-C_1}{C_0}$, where K is a numerical factor given in table below, C_0 is capacity for resonance (in secondary), and C_1 and C_2 are values of capacity for points on resonance curve for any pair of equal values of current. The table below shows the values of K for different values of the square of the ratio of the current γ_1 occurring with C_1 and C_2, to the maximum current γ_0 occurring with C_0, *i.e.*, when the circuits are in resonance.

In general the secondary is of course the wavemeter circuit, of which the decrement δ_2 and other constants are already known.

$(\gamma_1/\gamma_0)^2$	.90	.80	.75
K	4.71	3.14	2.72

If the primary circuit has a uniform H.F. current in it, δ_1 vanishes from the equation and δ_2 is obtained directly. If, however, the primary current is damped, a second determination must be made in which a known resistance R′ is introduced. Then the sum of the decrements becomes $\delta_1+\delta_2+\frac{R'}{2NL}=K\frac{C'_2-C'_1}{C'_0}$, giving a second equation in δ_1 δ_2, from which these may be determined by combining it with the first equation.

Damping of Aerials due to Radiation, &c.—[ZENNECK]:—

Umbrella - - - - - $\delta=.1$
Straight and T - - - - $\delta=.2$ to .3
Harp and Cone - - - - $\delta=.3$ to .4
Double Cone - - - - $\delta=.5$

Notes on Petrol Engines, Dynamos, and Accumulators.

Always pour your petrol into the tank through a strainer, for small solid particles may cause trouble in the carburettor.

Use a good quality of spirit, as (though almost anything will do in an emergency) you will very soon have trouble with the valves, &c., if you don't.

Study your engine till you know its weak points, and nurse them carefully.

If there is much sparking at the brushes of the dynamo, move them round the commutator until sparking is a minimum.

If the dark coloured marks usually called "flats" appear on the commutator, remove the brushes and polish with fine emery cloth, taking care that no emery gets into the bearings, finish with an oily rag, removing all dust.

Never discharge or charge your accumulators at greater rates than those stated by the makers. Never let the voltage of any cell drop below 1.85, and see that they are fully charged at least once a fortnight, even when not in use. Continue charging until the acid turns milky through the rapid evolution of gas from the plates. The density of the acid should be at least 1.195.

If the plates show signs of buckling, reduce the rates of charge and discharge, and examine them carefully from time to time in case short circuits should occur between adjacent plates.

Adhere strictly to any special instructions the makers may supply.

Notes on Ropes.

(From "THE GUNNER'S POCKET BOOK.")

Hemp Rope.—To calculate the working strain of rope, square the circumference in inches, and divide by 8 for the strain in tons.

To find the least size of rope to lift a given weight, multiply the weight in tons by 8 and extract the square root. The number found is the circumference in inches.

Wire Rope.—To find the safe strain for wire rope, multiply the square of the circumference in inches by .3 for iron, and .8 for steel wire. The breaking load is about three times the safe load.

Weight in lbs. per fathom is equal to the square of the circumference in inches. Thus 4-inch wire rope would weigh 4×4=16 lbs. per fathom.

Belcher-Hickman's Wireless Slide Rule.—This is an exceedingly useful little slide rule, by means of which the usual calculations necessary in wireless work can be made with great ease. It is published by the *Electrician* Co., of 1 Salisbury Court, Fleet Street, E.C.

Time Signals.—Daily time signals are now sent out from the Eiffel Tower and from Norddeich. The Eiffel Tower signals are as follows:—(1) a preliminary series of long slow dashes about a minute before 11.45 P.M.; (2) a pause of five seconds, and then one dot at 11.45 P.M. In a similar way there are other dots at two minutes past and four minutes past 11.45 P.M. These signals are also given at 10.45 A.M. The times at which these signals are to be sent will shortly be altered.

Norddeich sends on Greenwich time, using wave-length about 2,000 m., at midnight and midday. The signals consist of groups of five dots, the intervals between dots being one second; the last dot of the last group marks the hour. Norddeich has a high flute-like note.

The International Conference at Paris in October 1912 arranged that time signals should in future be sent out daily as follows:—

	Greenwich Time.		Greenwich Time.
Paris - -	0 h. midnight.	Norddeich -	12 h. midday.
San Fernando, Brazil -	2 h.	San Fernando, Brazil -	16 h.
Arlington, U.S.A. - -	3 h.	Arlington, U.S.A. - -	17 h.
Mogadiscio, Somaliland -	4 h.	Massowa - - - -	18 h.
Manila - - - -	4 h.	San Francisco - - -	20 h.
Timbuctoo - - -	6 h.	Norddeich - - -	22 h.
Paris - - - -	10 h.		

The signals will be on the following scheme: (1) During the first fifty seconds of the 58th minute (*i.e.*, the third minute before the hour), a series of x's. The 56th, 58th, and 60th seconds of this minute, and also of the 59th and 60th minutes, are marked by dashes each one second long; the last of these dashes, in the 60th minute, finishing exactly at the hour. In the 59th minute there is a dash occupying the 9th second and a dot on the 10th; this group being repeated every ten seconds. In the 60th minute there are dashes on the 7th and 9th seconds and a dot on the 10th; the group being repeated, as in the 59th minute, every ten seconds.

Sensibility of Telephones to Sounds of Various Pitch.—The following figures are taken from a paper by W. H. Eccles in the *Electron* (Siemens Inst., Stafford) of February 1909:—

N.	Current in Amps.	Ergs per Sec.	Sensibility.
64	1200.10^{-8}	116000.10^{-8}	.00028
128	160. „	3640. „	.012
256	13.5 „	56.8 „	.77
512	2.7 „	4.0 „	10.9
720	0.8 „	0.44 „	100.0
1024	1.35 „	1.4 „	30.3
1500	2.4 „	5.4 „	8.1

The currents given are those which just produce an audible sound, the maximum sensibility being taken as 100 per cent.

Dielectric Losses in Condensers.—Hahnemann and Adelmann have obtained the results represented in diagrams A and B by experiments with high-frequency currents.

θ = logarithmic decrement (no hysteresis).
$\Delta\theta$ = increase in decrement due to dielectric hysteresis.

Experiment shows that for a given potential gradient $\Delta\theta$ is independent of capacity and frequency. Fig. A gives relation of $\Delta\theta$ to watts per cm.^{3} of dielectric: *a*, *b*, *c*, *d*, are for rubber; *e*, paper; *f*, celluloid; *g*, ebonite; *h*, mica. Fig. B gives valuation of $\Delta\theta$ with square of potential gradient in kilovolts per millimetre: *a*, opal glass; *b*, flint glass; *c*, A. E. G. Leyden jar.

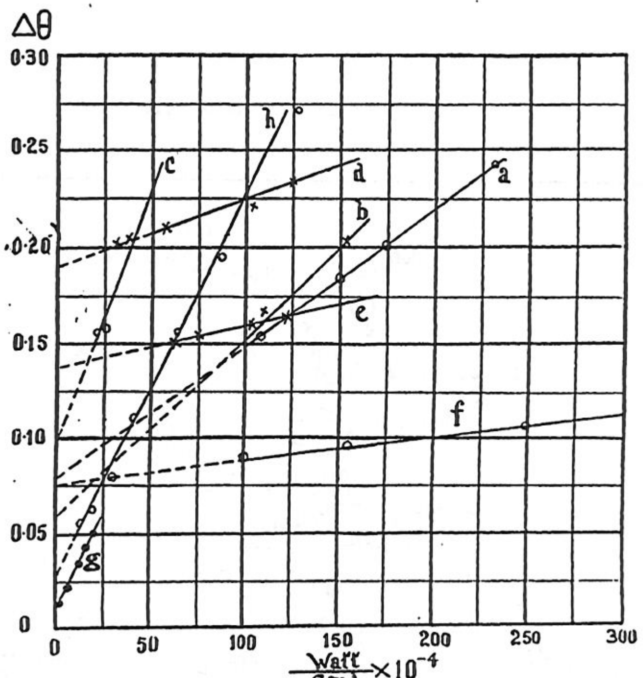


Fig. A.

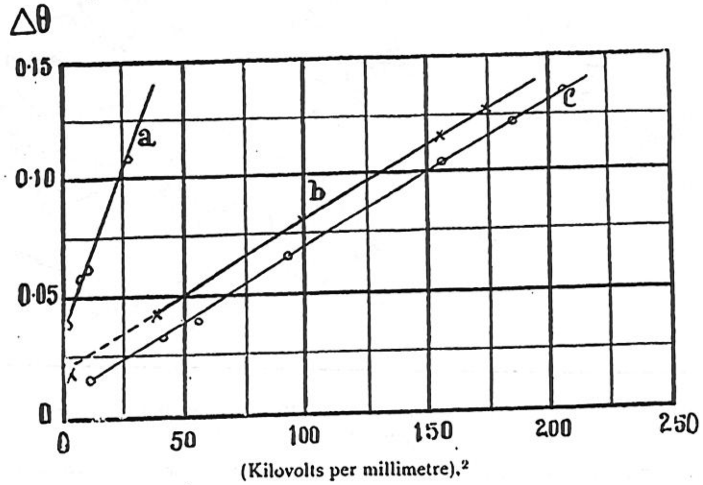
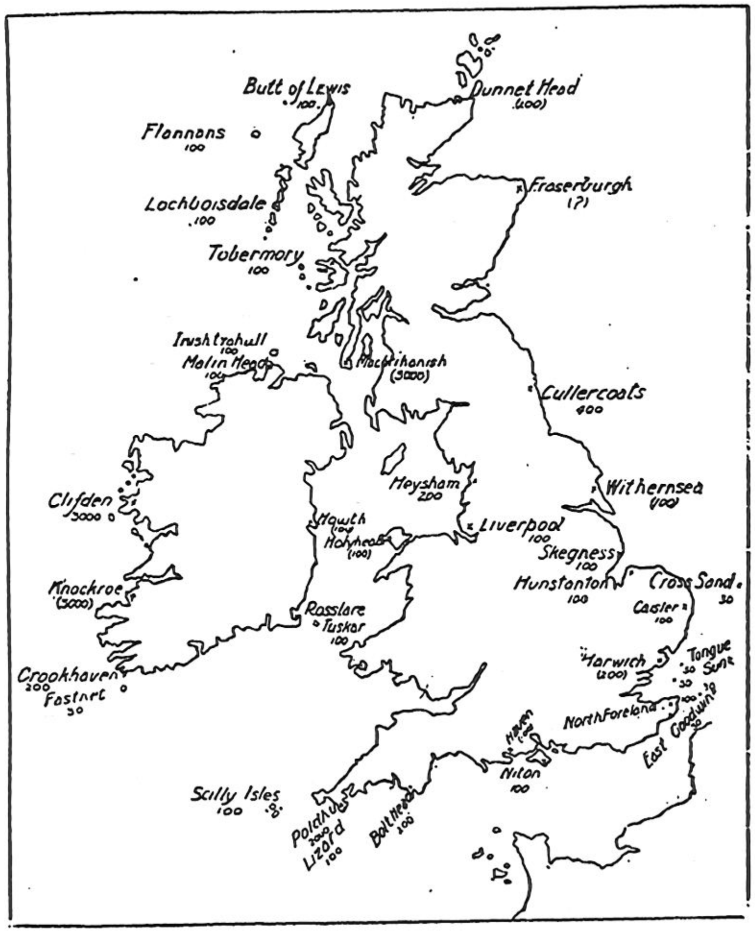


Fig. B.


Butt of Lewis
100
Dunnet Head
(400)
Flannans
100
Lochboisdale
100
Fraserburgh
(?)
Tobermory
100
Inishtrahull
100
Malin Head
100
Machrihanish
(3000)
Cullercoats
400
Clifden
3000
Heysham
200
Withernsea
(100)
Howth
100
Holyhead
(100)
Liverpool
100
Skegness
100
Knockroe
(3000)
Hunstanton
100
Cross Sand
30
Caister
100
Rosslare
Tuskar
100
Harwich
(200)
Tongue
30
Sunk
30
Crookhaven
200
Fastnet
30
North Foreland
100
East Goodwin
30
Haven
Niton
100
Scilly Isles
100
Poldhu
3000
Lizard
100
Bolt Head
100

COAST WIRELESS TELEGRAPH STATIONS OF THE BRITISH ISLANDS OPEN FOR PUBLIC USE.

The numbers indicate roughly the working ranges in miles; where they are in brackets the station is temporarily closed, or in course of erection.

Naval and Military Stations are omitted.

APPENDIX I.

THE INTERNATIONAL RADIOTELEGRAPHIC CONVENTION FOR THE CONTROL OF WIRELESS TELEGRAPHIC COAST AND SHIP STATIONS.

SERVICE REGULATIONS FROM 1ST JULY 1908.

1. Organisation of Radiotelegraph Stations.
2. Duration of Service at Coast Stations.
3. Form and Acceptance of Radiotelegrams.
4. Charges.
5. Collection of Charges.
6. Transmission of Radiotelegrams.
    (a) Signals.
    (b) Order of Transmission.
    (c) Calling of Radiotelegraph Stations and Transmission of Radiotelegrams.
    (d) Acknowledgment of Receipt and End of Work.
    (e) Route to be followed by Radiotelegrams.
7. Delivery of Radiotelegrams.
8. Special Telegrams.
9. Records.
10. Refunds and Reimbursements.
11. Accounts.
12. International Bureau.
13. Miscellaneous Provisions.

1. ORGANISATION OF RADIOTELEGRAPH STATIONS.

I.

The choice of the radiotelegraphic apparatus and arrangements to be used by coast stations and ship stations is unrestricted. The installation of these stations must keep pace as far as possible with scientific and technical progress.

II.

Two wave-lengths, one of 300 and the other of 600 metres, are allowed for general public correspondence. Every coast station open for this service employs one or other of these two wave-lengths. During the whole period for which it is open for service, every station must be in a position to receive calls made by means of its own wave-length, and it must not make use of any other wave-length for the service of general public correspondence. Nevertheless, each Government may authorise the use at any coast station of other wave-lengths for the purpose of providing a long-distance service, or a service other than that of general public correspondence, established in accordance with the provisions of the Convention, on condition that these wave-lengths do not exceed 600 metres or do exceed 1,600 metres.

III.

1. The normal wave-length for ship stations is 300 metres. Every ship station must be installed in such a way as to be capable of using this wave-length. Other wave-lengths may be used by these stations on condition that they do not exceed 600 metres.

2. Ships of small tonnage, which it would be materially impossible to equip with plant producing a wave-length of 300 metres, may be authorised to use a shorter wave-length.

IV.

1. By the agency of the International Bureau, a list shall be prepared of the radiotelegraph stations indicated in Article 1 of the Convention. This list shall give the following particulars regarding each station :—

(i.) Name, nationality, and geographical position in the case of coast stations; name, nationality, distinguishing signal under the International Code and indication of the ship's port of registry, in the case of ship stations;
(ii.) Call-signal (the call-signals must be distinguished from one another, and must each be composed of a group of three letters);
(iii.) Normal range;
(iv.) System of radiotelegraphy;
(v.) Nature of receiving apparatus (recording, sound-reading, or other apparatus);

(vi.) Wave-lengths used by the station (the normal wave-length is underlined);
(vii.) Nature of the service performed by the station :—
  General public correspondence :
  Restricted public correspondence (correspondence with the ships . . .; correspondence with the shipping lines . . .; correspondence with ships equipped with apparatus of the . . . system, &c.);
  Long-distance public correspondence;
  Private correspondence of the owners of the station;
  Special correspondence (correspondence of an exclusive official nature); &c.;
(viii.) Hours of service;
(ix.) Coast or ship charge.

2. The list shall also comprise such particulars with regard to radiotelegraph stations other than those indicated in Article 1 of the Convention as are communicated to the International Bureau by the Administration to whose authority these stations are subject.

V.

The stations indicated in Article 1 of the Convention are prohibited from exchanging superfluous signals and words. Trials and practice are only permitted at these stations in so far as they do not interfere with the service of other stations.

VI.

1. No ship station may be established or worked by any private enterprise without the authorisation of the Government to whose authority the ship is subject. This authorisation is given by a licence issued by that Government.

2. Every ship station which is authorised must satisfy the following conditions :—

(*a*) The system used must be a syntonised system;
(*b*) The speed of transmission and reception must, in normal circumstances, not be less than twelve words a minute, five letters being counted as one word;
(*c*) The power imparted to the radiotelegraphic apparatus must not, in normal circumstances, exceed one kilowatt. Power in excess of one kilowatt may be used if the ship finds it necessary to exchange messages at a distance of more than 300 kilometres from the nearest coast station, or if, by reason of intervening obstacles, communication can only be effected by an increase of power.

3. The service of the ship station must be carried on by a telegraphist holding a certificate issued by the Government to whose authority the ship is subject. This certificate testifies to the technical proficiency of the telegraphist as regards—

(*a*) The adjustment of apparatus;
(*b*) Transmission and sound-reading at a speed which must not fall short of twenty words a minute;
(*c*) Knowledge of the regulations applicable to the exchange of radiotelegraphic traffic.

4. In addition, the certificate testifies that the Government has bound the telegraphist to the obligation of preserving the secrecy of correspondence.

VII.

1. If an Administration has information of a breach of the Convention or of the Regulations committed at one of the stations which it has authorised, it shall verify the facts and fix the responsibility.

In the case of ship stations, if the responsibility falls on the telegraphist, the Administration shall take the necessary steps, and, if need be, withdraw his certificate. If it is proved that the breach was due to the condition of the apparatus, or to instructions given to the telegraphist, similar steps shall be taken with regard to the licence granted to the ship.

2. In the event of repeated breaches by the same ship, if the representations made to the Administration to whose authority the ship is subject by another Administration remain without effect, the latter is empowered, after giving notice, to authorise its coast stations to refuse communications from the ship in question. In case of difference between the two Administrations, the question shall be submitted to arbitration at the instance of one of the Governments in question. The procedure followed shall be that indicated in Article 18 of the Convention.

2. DURATION OF SERVICE AT COAST STATIONS.

VIII.

1. The service at coast stations is, as far as possible, permanent, day and night, without interruption.

Nevertheless, certain coast stations may provide a service of limited duration. Each Administration fixes the hours of service.

2. Those coast stations at which the service is not permanent must not close before they have transmitted all their radiotelegrams to such ships as are within their range of transmission, and have received from these ships all the radiotelegrams of which notice has been given. This provision applies also when ships notify their presence before work has actually ceased.

3. FORM AND ACCEPTANCE OF RADIOTELEGRAMS.

IX.

If part of the route followed by a radiotelegram lies over telegraph lines or through radiotelegraph stations belonging to a non-contracting country, the radiotelegram may be forwarded on condition that the Administrations of the countries to which these lines or stations belong have at the least declared their willingness to apply, when occasion arises, those provisions of the Convention and Regulations which are essential for the proper disposal of radiotelegrams, and provided also that adequate arrangements are made for accounting.

X.

1. Radiotelegrams bear the service instruction "Radio" in the preamble.

2. In the transmission of radiotelegrams from ship stations to coast stations the date and the time of handing in are omitted from the preamble.

On re-transmission over the ordinary telegraph system, the coast station inserts, as the indication of the office of origin, its own name followed by that of the ship, and gives, as the time of handing in, the time of receipt.

XI.

The address of radiotelegrams for ships at sea should be as complete as possible. It must contain the following:—

(*a*) Name of addressee, with further particulars, if necessary.

(*b*) Name of ship as it appears in the list, supplemented, in the case of ships bearing the same name, by the nationality of the ship, and, if necessary, its distinguishing signal under the International Code.

(*c*) Name of coast station as it appears in the list.

4. CHARGES.

XII.

The coast charge must not exceed 60 centimes a word, nor the ship charge 40 centimes a word.

A minimum not exceeding the coast charge or the ship charge for a radiotelegram of ten words may be fixed either for the coast charge or for the ship charge.

XIII.

A country on whose territory a coast station is established which serves as a medium for the exchange of radiotelegrams between a ship station and another country is considered, for the purpose of applying the telegraph rates, as the country of origin or of destination of those radiotelegrams and not as a country of transit

5. COLLECTION OF CHARGES.

XIV.

The whole charge for radiotelegrams is collected from the sender.

For this purpose ship stations must have the necessary tariffs. Nevertheless they have the right to obtain information from coast stations with regard to the assessment of the charge for radiotelegrams in respect of which they do not possess all the requisite particulars.

6. TRANSMISSION OF RADIOTELEGRAMS.

a. Signals.

XV.

The Signals used are those of the International Morse Code.

XVI.

Ships in distress make use of the following signal :—

· · · — — — · · ·

repeated at short intervals.

As soon as a station perceives the signal of distress it must suspend all correspondence and must not resume work until it has made sure that the communication consequent upon the call for assistance has been completed.

When a ship in distress adds, after a series of signals of distress, the call-signal of a particular station, the duty of answering the call rests with that station only. Failing any mention of a particular station in the signal of distress every station which perceives the call is bound to answer it.

XVII.

1. The call-signal followed by the letters · — — · · — · — · · ·, 'PRB," signifies that the ship or the station making the call wishes to communicate with the station called by means of the International Code of Signals.

The combination of the letters "PRB" is prohibited, as a service signal, for any other purpose than that above indicated.

2. The International Code of Signals may be used for radiotelegrams.

Those which are addressed to a radiotelegraph station for onward transmission are not translated by that station.

b. Order of Transmission.

XVIII.

Between two stations radiotelegrams of the same rank are transmitted separately in alternate order or in series consisting of several radiotelegrams, as may be determined by the coast station, provided that the time occupied in the transmission of any one series does not exceed twenty minutes.

c. Calling of Radiotelegraph Stations and Transmission of Radiotelegrams.

XIX.

1. As a general rule, it is the ship station which calls the coast station.

2. The call must only be made, as a general rule, when the distance of the ship from the coast station is less than 75 per cent. of the normal range of the latter.

3. Before beginning to call, the ship station must adjust its receiving apparatus to the highest possible degree of sensitiveness and make sure that the coast station which it wishes to call is not engaged in communication. If it finds that transmission is taking place it awaits the first break.

4. The ship station uses, for calling purposes, the normal wavelength of the coast station.

5. If in spite of these precautions the exchange of public radiotelegraphic traffic is interfered with, the call must cease at the first request made by a coast station open for public correspondence. This station must then indicate approximately how long it will be necessary to wait.

XX.

1. The call comprises the signal — · — · —, the call-signal of the coast station thrice repeated, the word "de" followed by the call-signal of the transmitting station thrice repeated.

2. The station called answers by giving the signal — · — · —, followed by the call-signal of the calling station thrice repeated by the word "de," by its own signal call, and by the signal — · —.

XXI.

If a station called does not reply as the result of the call (Article XX.) thrice repeated at intervals of two minutes, the call can only be renewed after an interval of half-an-hour, the station making the call having first ascertained that no radiotelegraphic communication is in progress.

XXII.

1. As soon as the coast station has answered, the ship station makes known—
    - (*a*) The distance of the ship from the coast station in nautical miles.
    - (*b*) Its true bearings in degrees reckoned from 0 to 360.
    - (*c*) Its true course in degrees reckoned from 0 to 360.
    - (*d*) Its speed in nautical miles.
    - (*e*) The number of words which it has to transmit.
2. The coast station replies by indicating the number of words which it has to transmit to the ship.
3. If transmission cannot take place at once the coast station informs the ship station approximately how long it will be necessary to wait.

XXIII.

When a coast station receives calls from several ship stations, the coast station decides the order in which the ship stations shall be allowed to transmit their correspondence.

The sole consideration which must govern the coast station in settling this order is the necessity of allowing every station concerned to exchange the greatest possible number of radiotelegrams.

XXIV.

Before beginning the exchange of correspondence the coast station informs the ship station whether transmission is to take place in alternate order or in series (Article XVIII.); it then begins transmission or follows up these service instructions with the signal — - — (invitation to transmit).

XXV.

The transmission of a radiotelegram is preceded by the signal — - — - — and terminated by the signal - — - — -, followed by the call-signal of the transmitting station.

XXVI.

When the radiotelegram to be transmitted contains more than forty words the transmitting station interrupts transmission after each

series of about twenty words with a mark of interrogation - - — — - -, and only continues transmission after having obtained from the receiving station the repetition of the last word duly received, followed by a mark of interrogation.

In the case of transmission by series, an acknowledgment of receipt is given after each radiotelegram.

XXVII.

1. When the signals become doubtful it is important that recourse should be had to all possible means for effecting transmission. For this purpose the radiotelegram is repeated, at the request of the receiving station, but not more than three times. If, in spite of this triple transmission, the signals are still unreadable, the radiotelegram is cancelled. If an acknowledgment of receipt is not received the transmitting station again calls the receiving station. If no reply is made after three calls, transmission is not continued.
2. If the receiving station, in spite of defective reception, thinks that the radiotelegram may be delivered, it inserts the service instruction "Reception doubtful" at the end of the preamble, and sends on the radiotelegram.

XXVIII.

All stations are bound to exchange traffic with the minimum expenditure of energy required for obtaining effective communication.

d. Acknowledgment of Receipt and End of Work.

XXIX.

1. The acknowledgment of receipt is given in the form prescribed by the International Telegraph Regulations preceded by the call-signal of the transmitting station, and followed by the call-signal of the receiving station.

The end of work between two stations is indicated by each station by means of the signal - - - — - — followed by its call-signal.

e. Route to be followed by Radiotelegrams.

XXX.

1. As a general principle, the ship station transmits its radiotelegrams to the nearest coast station.
2. Nevertheless, a sender on board ship is at liberty to indicate the coast station by which he desires his radiotelegram to be despatched.

The ship station then waits until this coast station becomes the nearest. If this condition cannot be fulfilled, the sender's wishes are only complied with if transmission can be effected without interfering with the service of other stations.

7. Delivery of Radiotelegrams.

XXXI.

When, for any reason whatever, a radiotelegram from a ship at sea cannot be delivered to the addressee, an advice of non-delivery is sent. This advice is transmitted, if possible, to the ship. When a radiotelegram reaching a ship station cannot be delivered, that station informs the office of origin by means of a service advice. This advice is transmitted, as far as possible, to the coast station through which the radiotelegram has been received, or, if the circumstances require it, to the nearest coast station.

XXXII.

If the ship to which a radiotelegram is addressed has not notified its presence to the coast station within the period indicated by the sender, or, failing such indication, before the morning of the 29th day, the coast station advises the sender to that effect.

The latter has the right to request, by a paid telegraphic or postal service message addressed to the coast station, that his radiotelegram may be retained for a further period of thirty days for transmission to the ship, and so on. Failing a request to this effect, the radiotelegram is treated as undeliverable at the end of the 30th day (the day of handing in not included).

Nevertheless, if the coast station knows that the ship has passed beyond its range of transmission before the radiotelegram could be transmitted to it, that station advises the sender accordingly.

8. Special Telegrams.

XXXIII.

The following are not admitted :—

(*a*) Telegrams with prepaid replies.

(*b*) Telegraph Money Orders.

(*c*) Collated telegrams.

(*d*) Telegrams with acknowledgment of receipt.

(*e*) Telegrams "to follow."

(*f*) Paid service telegrams, except as regards transmission over the ordinary telegraph system.

(*g*) Urgent telegrams, except as regards transmission over the ordinary telegraph system, subject to the provisions of the International Telegraph Regulations.

(*h*) Telegrams to be delivered by express or by post.

9. Records.

XXXIV.

The originals of radiotelegrams and the documents relating to them retained by the Administrations or private enterprises are preserved for at least twelve months, reckoned from the month following that of handing in, with all necessary precautions to secure secrecy.

These originals and documents are, as far as possible, sent at least once a month by ship stations to the Administrations to whose authority they are subject.

10. Refunds and Reimbursements.

XXXV.

1. Refunds and reimbursements are governed by the provisions of the International Telegraph Regulations, regard being had to the restrictions indicated in Article XXXIII. of the present Regulations, and subject to the following reservations :—

The time occupied in transmission by radiotelegraphy, and the time during which the radiotelegram remains at the coast station or at the ship station, are not reckoned towards the periods of delay which give rise to refunds and reimbursements.

The reimbursement is borne by the different Administrations or private enterprises which have taken part in the transmission of the radiotelegram, each Administration foregoing its proportion of the charge. Nevertheless, radiotelegrams which come under Articles 7 and 8 of the Convention of St Petersburg remain subject to the provisions of the International Telegraph Regulations, except when it is due to an error of service that such radiotelegrams have been accepted.

2. When the acknowledgment of receipt of a radiotelegram has not reached the station which transmitted the radiotelegram, the charge is only refunded after it has been proved that the radiotelegram is one which gives rise to reimbursement.

11. Accounts.

XXXVI.

1. The coast and ship charges do not enter into the accounts for which provision is made in the International Telegraph Regulations.

The accounts relating to these charges are settled by the Administrations of the Governments concerned. They are prepared by the

Administrations responsible for the coast stations, and are communicated by them to the Administrations concerned.

2. In respect of transmission over the ordinary telegraph system a radiotelegram is treated, for accounting purposes, in accordance with the International Telegraph Regulations.

3. In respect of radiotelegrams from ships the Administration responsible for the ship station is debited by the Administration responsible for the coast station with the coast and ordinary telegraph charges collected on board the ship.

In respect of radiotelegrams addressed to ships the Administration which has collected the charges is debited directly by the Administration responsible for the coast station with the coast and ship charges. The latter Administration credits the Administration responsible for the ship with the ship charge.

Nevertheless, in cases where the Administration which has collected the charges is that responsible for the ship station, the ship charge is not debited by the Administration responsible for the coast station.

4. The monthly accounts on which the special accounting in respect of radiotelegrams is based are prepared radiotelegram by radiotelegram, with all the necessary particulars, within six months from the month to which they relate.

5. The Governments reserve the right of making between themselves and in their dealings with private enterprises (organisations working radiotelegraph stations, shipping companies, &c.) special arrangements for the adoption of other methods of accounting.

12. INTERNATIONAL BUREAU.

XXXVII.

The International Bureau of Telegraph Administration will be entrusted, subject to the consent of the Government of the Swiss Confederation and to the approval of the Telegraph Union, with the functions specified in Article 13 of the Convention.

The additional expenses resulting from the exercise by the International Bureau of its functions in respect of radiotelegraphy must not exceed 40,000 francs per annum, not including extraordinary expenditure occasioned by the assembling of an International Conference.

These expenses form the subject of a special account, and the provisions of the International Telegraph Regulations are applicable to them. Nevertheless, pending the meeting of the next Conference, each contracting Government shall notify to the International Bureau the class in which it wishes to be included.

XXXVIII.

The various Administrations shall supply the International Bureau with a Return in conformity with the annexed model, containing the particulars specified therein in respect of the stations indicated in Article IV. of the Regulations. Subsequent modifications and additions shall be communicated by the Administrations to the International Bureau between the 1st and 10th of each month. By means of the information thus communicated the International Bureau shall prepare a list, and keep it up to date. The list and its supplements shall be printed and distributed to the Administrations concerned; they may also be sold to the public at cost price.

The International Bureau shall take care that the same call-signals are not adopted for different radiotelegraph stations.

13. MISCELLANEOUS PROVISIONS.

XXXIX.

The Administration shall facilitate arrangements for communicating to such maritime news agencies as they think fit such information respecting wrecks and shipping casualties, or of general interest for purposes of navigation, as can properly be communicated to them by their coast stations.

XL.

Traffic exchange between the ship stations indicated in Article 1 of the Convention must be so regulated as not to interfere with the service of coast stations, the latter being entitled as a general rule to priority for purposes of public correspondence.

XLI.

1. In the absence of special arrangements between the parties concerned, the provisions of the present regulations are applicable, by analogy, to the exchange of radiotelegraphic traffic between two ships at sea, with the following exceptions:—

(*a*) Article XIV.—The ship charge accruing to the transmitting ship is collected from the sender, and that accruing to the receiving ship is collected from the addressee.

(*b*) Article XVIII.—The order of transmission is settled on each occasion by mutual agreement between the communicating stations.

(*c*) Article XXXVI.—The charges in respect of the radiotelegrams in question do not enter into the accounts provided for in Article XXXVI., these charges being retained by the Administrations which have collected them.

2. The retransmission of radiotelegrams exchanged between ships at sea is subject to special arrangements between the parties concerned.

XLII.

The provisions of the International Telegraph Regulations are applicable, by analogy, to radiotelegraphic correspondence in so far as they are not inconsistent with the provisions of the present Regulations.

In conformity with Article 11 of the Convention of Berlin, these Regulations came into force on the 1st July 1908.

Official Handbook for Wireless Operators.

The British Post Office has published a small handbook containing full instructions to operators for the management of traffic in wireless stations. It contains among other matter the complete European Morse code and lists of service code signals.

International Conference of 1912.

The Conference which met in London in July 1912 revised some of the regulations and made some recommendations. The most important are as follows:—

1. Intercommunication obligatory between all ships irrespective of system.
2. All passenger ships except coasters to have wireless installation with continuous service in most cases.

The United States has now adhered to the Convention, and has passed strict laws enforcing the use of wireless on passenger ships.

ANNEXE TO ARTICLE XXXVIII. OF REGULATIONS.

Administration of..

PARTICULARS OF RADIOTELEGRAPH STATIONS.

(a) *Coast Stations.*

Name.	Nationality.	Geographical Position.	Call-Signal.	Normal Range.	System of Radiotelegraphy.	Nature of Receiving Apparatus (Recording Apparatus, Sound-Reading, or other Apparatus).	Wave-lengths (the normal Wave-length is under ined).	Nature of Service performed by the Station.	Hours of Service (showing the Meridian to which they refer).	Coast Charge, showing Minimum Charge.	Remarks.

(b) *Ship Stations.*

Name.	Nationality	Distinguishing Signal under the International Code of Signals.	Port of Registry.	Call-Signal.	Normal Range.	System of Radiotelegraphy.	Nature of Receiving Apparatus (Recording Apparatus, Sound-Reading, or other Apparatus).	Wave-lengths (the normal Wave-length is underlined).	Nature of Service performed by the Station.	Hours of Service.	Ship Charge (showing Minimum Charge).	Remarks.
1. *Ships of War.*												
2. *Merchant Ships*												

APPENDIX II.

THE IMPERIAL WIRELESS STATIONS.

DRAFT SPECIFICATION.*

THE following are the more interesting points dealt with in the specification :—

TRANSMITTING STATIONS.

1. The installation to be designed for efficient transmission at full power, and to be capable of transmitting to the distant station, with which it has to communicate, at all times of the day and night.

2. The wave-lengths of all stations in connection with the imperial scheme shall be as great as possible within the limits of 17,000 ft. and 50,000 ft. (consistent with keeping the capacity inductance and size of the aerials within reasonable limits) in order to ensure reliability of reception at all times of the day and night, but the wave-lengths transmitted from any one station will be in all cases at least 25 per cent. different from those transmitted from other stations within its normal range, and with which it has to communicate. In the case of the English station, the wave-length chosen for communication with Egypt will be 30,650 ft. approximately. In all cases throughout the imperial scheme there will be a difference of 5 per cent. between the wave-lengths emitted from any one station in order that each corresponding receiving station with which this station has to communicate may be able to tune out the waves emitted by the said station for the other station or stations with which it is also communicating. In the case of the English station the above-mentioned wave-length of

---

* To the Contract of 1913 no specification is attached leaving the Marconi Company free to employ any apparatus considered suitable. The following formed part of the 1912 Contract, now superseded.

30,650 ft. has been chosen in order that there will be no mutual interference with other high-power stations existing or in contemplation within the range of the English station.

3. The characteristics of all the stations will be so chosen that each station shall be capable of communicating with its respective corresponding stations at all times. In order to effect this the station will be designed with high aerials and considerable reserve of power over what is required theoretically to bridge the respective distances.

4. Where a station is required to communicate in more than one direction, separate transmitting circuits to be provided, and in such cases the characteristics of each transmitting circuit will be identical, except in so far as it is necessary to vary the inductance of the H.F. circuit according to the wave-lengths to be transmitted.

5. The note of each station shall be different from those of any other station within its range, but the notes of each transmitting circuit in any one station shall be identical. Facilities shall be provided, however, for slightly altering the note of any one of the transmitting circuits in case it may be found at any time desirable to do this.

6. In order to standardise the apparatus so that the staff of one station shall be equally competent to look after the plant of another station, the power plant and heights of the aerials and types of machines and apparatus shall be, as far as practicable, the same in each case, and the types of prime mover and generator shall be, where possible, identical in each case.

7. *Aerials.*—The size of the aerials in each case to depend upon the length of wave emitted. The capacity of the aerial shall be such that under working conditions the voltage shall not rise sufficiently to produce a bright brush discharge. The length of each wire used in the aerial shall be electrically identical, and the wires shall be insulated throughout their length. The transmitting aerial to be of the multi-wire directional type—*i.e.*, with the centre line through the horizontal portion of the transmitting aerial coinciding with the line of direction of the station with which it is required to communicate, the free or elevated end of the aerial pointing directly away from the communicating station. The English aerial to consist of a number of parallel wires, each wire being composed of seven strands of No. 19 S.W.G. silicon-bronze wire. Each wire will be over 3,000 ft. long, and insulated throughout its entire length. The aerial will be supported by ten sectional tubular steel masts, each 300 ft. high. The aerial will be suspended from the various triatics by means of porcelain rod and reel insulators. The aerial will pass freely through the porcelain reel which is attached to the bottom of the porcelain rod insulator. The triatics will be made of 1½ in. circumference extra flexible steel wire rope having a breaking strain of 7½ tons.

8. *Masts.*—The masts for supporting the aerial shall be of the 2 ft. 6 in. sectional steel tubular type, and shall be 300 ft. high in each case. The aerials to be supported on triatics stretched between pairs of masts. Each mast to be capable of withstanding a permanent horizontal strain of not less than 2 tons at the head of the mast, in addition to windage calculated at the rate of 30 lbs. per effective square foot. The masts will be provided with a suitable number of steel wire guys insulated from the masts and attached to anchor blocks set in the ground.

9. *Earth System.*—This system to consist of a series of galvanised iron plates buried in a suitable position relatively to the station house. This arrangement to be supplemented by a number of horizontal wires running to the boundaries of the site. The set of plates outside the building to be connected by suitable leads and carried into the building and thence to the various circuits.

10-19. *Power Plant.*—The power plant to be in duplicate, and to include two steam boilers (each capable of evaporating sufficient water for the whole requirements of any one transmitting circuit). In the case of stations required to send in two directions three boilers are to be provided; and in the case of stations, such as the one in East Africa, required to transmit in three directions at the same time, the station is to be provided with four boilers.

It is mentioned that the prime mover in each case to be a steam turbine, direct coupled to an alternating-current generator, which in turn will be coupled direct to a Marconi revolving disc discharger. Excitation for the alternators will be provided by two 110-volt turbo-generators, which will also supply the lighting of the building, fans, &c. The total power at the terminal stations to be 1,300 H.P., and at the intermediate stations to vary from 1,900 H.P. to 2,500 H.P., according to the locality, range, and number of directions in which transmission is required.

Each boiler to be of the water-tube type, to have a grate area of not less than 3,000 sq. ft., to be designed for a working pressure of 200 lbs. per sq. in., and to be provided with superheaters capable of raising the temperature of the steam by 200° F. of superheat.

The condensing plant to be in duplicate and of the surface type.

20. *Transformers.*—Each station to be provided with five transformers for each transmitting circuit.

21. *Inductances.*—The inductances for regulating the condenser charging circuit to be of the Marconi latest improved air-core type. Other air-core inductances to be provided, placed in the leads from

the secondary inductances to the condensers for the purpose of preventing surges of voltage being set up in the transformers.

22. *Shunt Protectors.*—Shunt protectors of the graphite or lamp type to be provided as shunts across the windings of the fields and armatures of all machines in the station, in order to prevent oscillations being set up in the various windings of these machines.

23. *Condenser Bank.*—The station to be provided with a separate condenser bank for each transmitting circuit, consisting in the case of the English station of 540 cells. Each cell to be of special and improved design, consisting essentially of the same number and type of plates as in the original Poldhu jar type of condenser, but these plates to be mounted in a special form of ironstone containing vessel. The containers to be self-insulating, thus dispensing with the necessity for the provision of insulated stands. Further, the lids of these containers to be provided with a heavy oil seal to prevent the internal insulation being affected by moisture reaching the inside of the condensers. Each cell to be provided with high-tension terminals connected to the plate lugs and formed to take the external bus bars in a convenient fashion. The connections between the individual cells will be formed of copper strip. The whole design of the transmitting circuit to be such as to obviate the necessity of any changing in the grouping of the condenser cells, the capacity in this circuit being kept at a fixed value, and any required variation in wave-lengths being obtained by regulation of the inductance of the jigger primary winding or the connections thereto. The main bus bars from the condenser to lead to the jigger and discharger and to be so arranged as to reduce the inductance of these leads to as low a figure as is required. The leads from the bus bar connections to be so arranged that the spare alternator and disc can be quickly connected thereto and the other disc disconnected.

24. *Disc Discharger.*—The station to be provided with one disc discharger for each transmitting circuit and one spare. Each discharger to be of the Clifden type, modified to suit the requirements of this service, with special slide electrodes, and provided with the necessary number of studs. The disc will be provided with an insulated coupling between the disc and alternator shaft, and means will also be provided for driving the disc from an independent motor.

25. *Transmitting Jigger.*—One transmitting jigger to be provided on each circuit for use on the full power of the installation, the jigger to be provided with a multi-stranded primary conductor arranged in conformity with the latest type of jigger as used at our Clifden station, the secondary of this jigger to consist of a special solenoid winding of similar cable to the primary winding but of smaller size. The primary and secondary windings to be entirely separate, and the secondary to move laterally with regard to the primary to enable the coupling of the two circuits to be varied.

26. *Aerial Tuning Inductances.*—The stations to be provided with aerial tuning inductances of an approved design.

27. *Signalling Gear.*—The station to be provided with not less than three relay operating high-tension signalling switches on each transmitting circuit, which will be inserted on the lead from the low-frequency inductance to the condenser bank, thus affording control over the charging current to the high-frequency primary circuit. Above the high-tension signalling switches will be installed isolating switches to enable any of the switches to be connected or disconnected at will. The electro-magnets of the high-tension signalling switches will be operated by means of a relay current, the relay being situated in the transmitting station. The relay will, however, be operated by means of a Morse hand key, situated in the operating station several miles away. The relay will also be capable of being operated by means of a Wheatstone or other automatic transmitter, also situated in the operating house, and means will be provided to enable the operation to be carried out by hand or automatic at will. The transmitting station will, however, be provided with a Morse hand key to enable signalling to be carried out from the transmitting station should it at any time be necessary to do so.

RECEIVING AND OPERATING STATIONS.

The receiving and operating station to be situated at a distance of not less than 10 miles from the transmitting station.

Receiving Aerials.—The receiving aerials to consist of one or more silicon-bronze stranded conductors supported by sectional steel masts 300 ft. high. The receiving aerial to be erected parallel with the centre line of the transmitting aerial. The receiving aerial wires in the case of the English station will be approximately 8,000 ft. long.

Masts.—The receiving aerial will be supported by sectional steel masts each 300 ft. in height, the masts to be of the sectional tube pattern, efficiently guyed and connected to anchor blocks by flexible steel wire stays suitably insulated from the masts.

Earth System.—The earth system to consist of a number of galvanised iron plates buried in a suitable position relative to the receiving house, and at a radius of 200 ft., and connected to the receiving circuit by a number of radial galvanised iron wires, the earth system being further supplemented by a number of similar wires attached to the outer plates and running below the horizontal portion of the directional receiving aerial.

Operating and Receiving Gear.—The operating room to be furnished with Morse hand keys and Wheatstone or other similar type of automatic transmitters with suitable switch arrangements, so that operating can be effected either by automatic transmitter or by hand key.

The receiving station shall be further provided with a small outbuilding containing a 5-H.P. petrol engine, coupled to a direct-current dynamo, for supplying lighting to the building and current to the operating line. A storage battery of adequate capacity also to be installed, so that current can be taken from the battery or generator at will.

INDEX.

ABNORMAL distances, 301, 304
Absorption diagram, Zenneck's, 293, 295
Absorption in travelling over various soils, 292
  of layers of soil, 295
Acoustic tuning, 377
Aerial capacities, Lodge-Muirhead, 163
  damping, 407
  wire, current in, 385
  wire, length of, 382
Air, ionization of, 308
  Thomson on conductivity of, 307
Alaska, wireless telegraphy in, 197
Alps, effect on transmission, 302
Alternator, frequency of, and spark rate, 70
  Tesla's high frequency, 49
Aluminium, properties of, 403
Amplitudes for resonance, 252
Andaman Islands installation, 168
Antennas, 221
Anti-coherers, 89
Arc, characteristic curve, 56
  Duddell musical, 201
  unstable, as generator of H.F. currents, 57
Arco, inventions of Count, 45
Arcs, no applied magnetic field, 60
Armstrong and Orling, electro-capillary detectors, 136
Artom, directive system, 233
Atmosphere, electrical properties of, 263
  height of conductive layer, 264, 273, 329
Atmospheric electricity, charge on aerial wire, 41
  electricity, variations of, 256
Atmospherics, 310
Audibility of signals, 349
Auroræ, recent observations of, 274
Austin on audibility of signals, 349
  on earth connection, 222
  on Marconi magnetic detectors, 94
  on measurements of long distance transmission, 298
  on vacuum valve, 130

BARKHAUSEN on "Production of Vibrations," 64
Barkhausen on measurements of sending and receiving currents, 299
Beat currents, 256
Bellini and Tosi receiver, 232
  system directive telegraphy, 233
Bellini-Tosti wireless compass, 226
Blondel, propagation of waves, 273
Bolometer, Tissot's form, 115
Brandes on damping, 357
Branly, coherer, 74
Braun, inventions of Professor, 45

Braun's cathode ray oscillograph, 61
  oscillograph, 64
Brown, S. G., Hozier-Brown system, 191
Brylinski, penetration of currents, 269
Buenos Aires de Clifden, 151
Burstyn, inventions of W., 215
  on height of lower capacity, 174
  on units, 397

CAPACITY, importance of, 11
Cape Cod, Marconi station, 137
Capillary detectors, 136
Carborundum detector, 126
Chambers' de-tuning circuit, 220
  ,, harmonic selector, 220A
Characteristic curves, various types, 63
  curves, determination of, 64
  (Energy) curve, condenser method of determining, 64
  (Energy) curve, inductance method of determining, 64
  curves of uniform H.F. currents, 61
Clerk-Maxwell, wave theory, 14
Clifden, Marconi station, 137, 146, 150, 151
Closed circuit system, 2, 6
Coherence, force of, 74
Coherer circuit, current in, 391
  circuit, measurements of voltage in, 90
Coherer, discovery of, 33
  influence of applied voltage, 78
  Lodge-Muirhead wheel, 89, 158
  Marconi filings, 75
  speed of action, 73
Coherers, characteristic curves of filings, 83
Compagnie Générale Radiotelegraphique, 215
Compass, Bellini-Tosi, wireless, 226
  Telefunken, wireless, 235
Conduction through a gas, 55
Conductivities, 396
Connections, earth, 225
Coupled circuits, 255
Coupling coefficient, 257, 360
  percentage, 262
  relation to energy transmission, 257
Cram, 149
Crystalline rectifiers, 125
Currents, H.F., production of, 48
Current and voltage in antenna, 381
Current and E.M.F. in wave, 299
Cymometer, Fleming, 353

DAMPING, 253, 254, 354
Damping, Brandes, 357
Damping, cause of, 28
  of aerials, 407
  curve, 254
  curve, definition of, 240, 243, 397
  from resonance curve, 356
  measurement of, 353
  Monasch, 359
  Rutherford, 335
  Tissot, 355
  Traubenberg, 357, 359
Day and night transmission difference, Marconi's discovery of, 137
  and night variations in transmission, 266
  and night ranges, theory of, 305
  and night ranges, Edwards on, 304
Daylight to darkness transmission westward, Marconi's observations, 301
Decrement, logarithmic, 240, 397, 404, 407, 410
De Forest directive aerial, 228
  electrolytic detector, 131
  system, 229
  Audion, 136
Detectors, Austin on vacuum valve, 130
De-tuning circuit, Chambers', 220
Dielectric constant of ground, 288
Direct coupling, 43
Directed systems, 227

Directive aerials, Zenneck's theory of, 232
  telegraphy, theory of, Zenneck, 235
  transmission, 364
Direction of radiation, determination of, 226
Dissipation of energy in transmission, 282, 292, 301
Dolbear system, 33
Double reciprocating circuit generator, Marconi's, 55
Dowse's method of measurement, 342
Duddell, 59, 149
  and Taylor, Irish Channel experiments, 274
  thermo-galvanometer, 119
Duddell musical arc, 201

EARTH connections, Austin on, 222
Earth connections, 225
Earth, on resistance of the surface of, 221
  period of vibration of, 312, 329
  return, 2
  resistance of, 264
  resistance, determination of, 367
  resistance and other constants of a transmitter, experimental method for the determination of radiation efficiency, 367
Eccles, the effects of jigs on iron, 104
  on filing coherers, 78
Edwards on day and night ranges, 304
Efficiency, energy, 363
  Erskine-Murray's method for determination of, 367
  of Lodge-Muirhead system, 171
  of wireless transmission, 361
  operative, 361, 374
  telegraphic, 361, 377
  Zenneck on, 370
Eiffel Tower time signals, 409
Electrolytic detector, De Forest's, 131
  Fessenden's, 133
  Pupin's, 132
E.M.F. in wave and current in antenna, 299
Energy efficiency, 363
Epstein, wave forms, 297
Erskine-Murray's method for determination of efficiency, 367

FEEBLY damped circuits, 254
Fessenden generator, 54
Fessenden barreter, 114
  electrolytic detector, 132
  magnetic detectors, 95
Fessenden system, 175
  variations in transmission, 269
Fitzgerald, period of electrical oscillation of earth, 312
Fleming, hot carbon rectifier, 135
Frequency, definition of, 239, 243, 397

GALENA, 132
Galletti system, 219
Garcia, directive aerial, 228
Gaseous section in circuit, generation of H.F. currents, 53
Generator, Lepel, 56
Generator, unstable arc, 57
Gibson on graphs, 238
Glace Bay, Marconi station, 137, 145
Goldschmidt high frequency dynamo, 50
  static frequency converters, 52
  system, 209
Gray, sending key, 140
  J. H., slow oscillations, 242

HACK on absorption by layers of soil, 295
Handbook, P.O. official, 426
Harmonic selector, Chambers', 220A

Heavily damped circuits, 255
Heaviside, propagation of waves, 273
Henry, Joseph, researches, 8
Hertz, researches, 13
  vibrator, 9, 15
  wave diagrams, 18
Hettinger, limits of non-interference, 30
Hickman's wireless slide rule, 409
High frequency dynamo, Goldschmidt's, 50
Horizontal aerial, waves from, 237
Hozier-Brown detector, 191
  system, 191
Hughes, discoveries, 8
Hysteresis losses, 24
  dielectric, 410

INDUCTANCE, importance of, 11
  formulæ for, 402
  Induction coil, action of, 66
Induction coil, resonance, 68
Ionization of air, 308
Insulators, oil, 27
Intensity of transmission, variations of, 189
Interference preventer, Fessenden's, 182, 187
Interrupter, Hammer, 69
  Lodge-Muirhead, 161
  Mercury, 69
  Wehnelt, 68

JACKSON, Captain H. B., early experiments, 36
  experiments on screening, 271
  variations in transmission, 266
Jig, definition of, 113
Jigger with split secondary, 247
Jiggers, functions of, 41
Joly, static frequency converters, 52
Joulean and radiation resistances, 224

KELVIN on oscillatory currents, 240
  Kelvin, electrical images, 273

LECTURE, Marconi, 145
  Lepel, shock excitation system, 211
Lepel system, 55, 211
Leyden jar circuits, Lodge's, 9
Lindemann measurement of resistance at high frequencies, 344
Lindsay system, 2
Lodge, electro-magnetic system, 3
  first experiments, 22
  resonating Leyden jars, 9
  syntonic system, 36, 44
Lodge-Chambers' system, 220
Lodge-Muirhead, Andaman Islands installation, 169
  description of system, 154
  system, 3
Logarithmic decrement, 240, 243, 354, 397, 404, 407
Lower capacity, height above earth (Lodge-Muirhead), 174

MACHRIHANISH, Fessenden station, 176
Magnetic detector, Austin on Marconi, 94
  Fessenden's, 95
  Marconi's, 92
  Walter's, 97
Marconi coherer, 75
  day and night variation, 137, 281, 301
  description of system, 137
  early experiments, 40
  experiments on directive telegraph, 232
  earth connection, 37
  first receiver, 39
  long range stations, 137

Marconi magnetic detectors, 92
  on strength signals, 303
  system, 36
  tuner, 144
  uniform H.F. current generator, 147
Marillier, description of Lodge-Muirhead system, 154
Maskelyne, aerial, 46
Measurement of damping, 354
Measurements of sending and receiving currents, Barkhausen on, 299
  resistance at high frequencies, Lindemann, 344
Molybdenite, 126
Monasch, damping, 359
Montel, Alfredo, calculation of syntonic station, 378
Morse codes, 395
Morse system, 2
Musical arc, Duddell, 59
  code signals, 215
  spark, 213, 216

NAUEN, station at, 219
  Newfoundland, de Poldhu, 137
Night and day ranges, Edwards on, 304
  and day ranges, theory of, 305
Non-interference, limits of, 30
Norddeich time signals, 409
Norfolk, Va., and San Francisco, transmission between, 309
Numerical distance, Sommerfeld on, 296

O'MEARA, Major W. E., 369
  Open circuit telegraphy, 5, 7
Operative efficiency, 361, 374
  efficiencies as regards tuning, 376
Oscillograph, Braun's cathode ray, 61
  Braun's, use of, 64
Oscillatory currents, Kelvin on, 240

PACHENA POINT, B.C., and Victoria, B.C., communication between, 304
Parabolic mirrors, Marconi's experiments with, 227
Pedersen's high-speed transmitter, 204
  "tikker," 204
Percentage coupling, 262
Period, definition of, 239, 243, 397
Peukert system, 215
Phase difference, directive aerial, 227
  difference of vertical and horizontal components of electric force, 290
"Philadelphia," S.S., Marconi's experiments on, 137
Pierce on detectors, 126
Plane polarised waves, 16
Popoff receiver, 22
Potentiometers, liquid, 79
Poulsen generator, 53
  system, 201
Preece's system, 7
Pupin, electrolytic detector, 132

QUENCHED spark systems, 211, *et seq.*

RADIATION and Joulean resistances, 224
Radiation, coefficient, 223
  efficiency, determination of, 367
  resistance, 223, 367
Radiogoniometer, 232
Range of communication, limit of, 284
Ranges, day and night, Edwards on, 304
  day and night, theory of, 305
Rate of sparking, Duddell and Taylor, 249
  of sparking, Tissot, 250

Ratio of vertical and horizontal components of electric force, 290
Rayleigh on construction of transformers, 246
Receiver, Lodge-Muirhead, 166
  circuits, currents in, 389
Record for long distance, 151
Rectifiers, crystalline, 125, 126
Reflection of waves, 16
Refraction of waves, 16
Reich, potential gradients under antenna, 222
Reliability in telegraphic working, 375
  of wireless telegraphs, 198
Resistance at high frequencies, Lindemann's measurements of, 344
  distribution of, near Howth, 287
  effects of unsymmetrical distribution of, 286
  of the surface of the earth, 221
  of antennas, 223, 367
Resonance curves, 253, 256, 356, 358
  curves, uniform H.F. applied voltage, 251
  induction coils, 68
Resonating transformer, Tesla, 248
Revibration, natural frequency, 24
Rhone valley, effect on transmission, 303
Robertson, electrostatic lines of force, 77
Russell, magnetic oscillations, 106
Rutherford, early experiments, 32
  experiments on radiation, 91
  on damping, 355

SAND, observations on electrolysis, 134
Screening, Jackson's experiments on, 271
Sea, resistance of, 265
Secondary circuit, absorption of energy, 251
Secrecy-sender, Fessenden's, 183
Sella-Tieri, magnetic detector, 112
Sending key, Fessenden, 175
Sharpness of tuning, 255
Ship's bearings, determination of, 235
Shock excitation systems, 211
Signals, strength of, Marconi on, 303
  audibility of, 349
Silicon detector, 126
Simple harmonic motion, 238
Simpson, report on Burmah and Andaman Islands installation, 168
Slaby, double earth connection, 45
  transmitter, 47
Slide rule, Hickman's, 409
Sommerfeld, numerical distance, 296
  theoretical ranges deduced by, 309
Snow Harris, thermo-galvanometer, 119
Soils, absorption in transmission over, 292
Solari mercury coherer, 89
Spark discharges, 65, 67
  rates, Lieut. Tissot on, 250
  rate, high, Webb's system, 72
Space waves, 296
Speed of transmission, 376
Static frequency converters, 52
Stationary waves, Tesla's observation of, 316
  vibrations, 12
Superposition of periodic motions, 28
Surface waves, 296
Sutton, Galena detector, 128

TABLES—
  accumulators, notes on, 407
  capacity of vertical wires, 400
  condensers, capacity of, 397. 399
  damping, effect on resistance, 404
  inductance of helices, 400
  inductivities of materials, 396
  insulators, strength of, 396
  Morse codes, 395
  resistance, straight copper wires, 403

Tables—*contd.*
  ropes, notes on, 409
  spark lengths, 405
  spark resistance, 404
Tapper, automatic, 76
  Marconi's, 39
Taylor on atmospherics, 311
Taylor, J. E., 369
Telefunken, shock excitation system, 211
  system, 46, 211
  wireless compass, 235
Telegraphic efficiency, 361, 377
  working, reliability in, 375
Tesserenc de Borc, 307
Telephones, sensibility of, 410
Tesla, Colorado Springs experiments, 314
  detector, 323
  H.F. transformer, 25
  proposed syntonic system, 35
  researches, 23
  sensitive ray, 27
  wireless telegraph proposed 1893, 314
  world-wave system, 316
Testing—
  capacity, 337
  condensers, 340
  continuity of conductors, 331
  damping, 354
  frequency, 350
  induction coils, 333
  insulation, 332
  interrupters, 336
  receivers, 334
  relays, 345
  transmitters, 335
  wave-length, 350
Thermo-galvanometer, Duddell's, 120
Thermometric detectors, 113
Thomson on conductivity of air, 307
Time signals, daily, 409
"Tikker," Pedersen's, 204
Tissot, bolometer, 114
Torikata on detectors, 126
Train of waves, effect of, 29
Transatlantic communication, Marconi's, 137, 148
  Fessenden's, 188
  stations, 145, 188
  Poulsen, 209
  Goldschmidt, 210A
Transformer, Tesla's tuned, 66
Transformers, receiving, 244
Transmission along conductive stratum of atmosphere, 309
  day and night variations, 266
  directive, 364
  dissipation of energy in, 282
  efficiency of wireless, 361
  over sea, Austin's measurements of, 298
  recent researches on, 295
  speed of, 376
  theories of, 263
  westward, day to night, Marconi's observations, 301
Transmitter, high-speed, Pedersen's, 284, 209
  power, relation to distance, 180
Trouton, date of experiments, 36
True, on earth resistance, 225
  on potential gradients under antenna, 222
Tuning, 41
  acoustic, 377
  as regards operative efficiencies, 376
  sharpness of, 255

ULLER, horizontal aerial, 236
  Uniform alternate current systems, 201
Uniform currents, detection of, 203
  H.F. currents, characteristic curves of, 61
  jig producer, Brown's, 194

a turbine pump against a species of revolving toothed wheel which is connected to the other electrode. The teeth are tapered, so that by adjusting the position of the jet which plays against them, longer or shorter contacts may be made. The chief disadvantage of this type is, that the mercury becomes churned up with the petroleum or other insulating liquid in the jar, and rapidly forms a sticky mess which must be periodically cleaned out and purified. In a laboratory, with conveniences for chemical work, this is not a serious drawback, but in a wireless telegraph station—possibly one room in a cottage, many miles from even a village—it is a great objection, especially as while the apparatus is being cleaned, there is no possibility of answering a call, or of sending an urgent message. For these reasons, mercury breaks have not entirely superseded the other forms of interrupter mentioned, though they have frequently been used on account of their uniformity of action for short periods; *i.e.*, before the mercury and oil have become appreciably mixed.

In wireless telegraph stations, where continuous current is used, the interrupters in most general use are the hammer and the mercury turbine, but interrupters are being dispensed with entirely in many stations by the adoption of alternate current machinery. In the earlier stations the source of electric energy was usually a battery of, say, fifty large dry cells, used perhaps in combination with a portable accumulator. Nowadays it is more common to have a small oil or petrol engine and alternator in conjunction with some high tension transformers, instead of a battery and induction coil. The frequency of the alternator is not related to the frequency of oscillation, and only indirectly to the number of sparks per second. The actual rate of sparking is not in general exactly twice the frequency of the alternator, as might have been expected from the occurrence of a positive and a negative maximum each period, but may be much greater; in fact, there may be as many as ten sparks per alternation. This is probably due to electric surging in the

circuit; *i.e.*, oscillations of shorter period superposed on the wave given by the alternator. The phenomenon depends on the induction in the leads from the transformer to the spark-gap and the capacity charged. Inductance must be introduced in these leads, otherwise an arc would be formed which would be useless for the creation of jigs. Inductance, however, checks the supply of current when the spark has commenced and the dropping of the voltage causes its sudden but oscillatory extinction. The phenomenon may thus occur several times during each period of the alternator. This subject has been investigated by Professor Fleming, by means of an ingenious spark counter which he has devised for the purpose.*

In stations run by alternating machinery the current is generated at a low voltage, and is transformed to the very high voltage necessary by means of one or more transformers. These must have high ratios of transformation, and of course very good insulation. A potential of about 30,000 volts or more is common in such work, though some inventors, notably Professor Fessenden, are understood to be using lower voltages.

The alternator is usually run at such a speed that a musical note is produced by the succession of sparks. In other cases a musical note is produced by making the sparks occur between a fixed electrode and a revolving disc with knobs on it. The advantage of the note is that any station may be distinguished by the pitch and quality of its note as heard in the receiving telephone at the corresponding station. The operator can thus distinguish the signals he wishes to read although others may be audible.

High Spark Rates.—A number of modern high frequency current detectors are capable of summing up, or integrating, the effects of a succession of electric

---

* "Electric Wave Telegraphy," p. 157, J. A. Fleming (Longmans).

VACUUM valve detectors, Austin on, 130
Vallauri, static frequency converters, 52
Variation of received current with distance, 280
Vector wave diagrams, 291
Vibrations, complex, 31
Voltage and current in antenna, relation between, 381
Von Bezold, researches, 11

WALTER and Ewing, magnetic detector, 97
Walter, magnetic detector, 101
Wattless current in primary of transformer, 199
Wave chute, Fessenden's Machrihanish, 178
Wave forms, Epstein on, 297
Waves along wires, velocity of, 31
Webb's system, 72
Wien, M., on hissing sparks, 211
Wildman, Captain L. D., 197
    Captain, variations in transmission, 267
Willoughby-Smith system, 2
World-waves, Fessenden on possible, 330
    Fitzgerald on possible, 312

X-STOPPER, Marconi's, 144
    X's, or atmospherics, 310

ZENNECK on efficiency, 370
    Zenneck's theory of transmission, 289
Zincite-Chalcopyrite detector, 128

Printed at THE DARIEN PRESS, *Edinburgh.*

L

CROSBY LOCKWOOD & SON'S

LIST OF WORKS

ON

CIVIL, MECHANICAL, MARINE AND ELECTRICAL ENGINEERING.

A Complete Catalogue of NEW and STANDARD WORKS on MINING and COLLIERY WORKING; ARCHITECTURE and BUILDING; The INDUSTRIAL ARTS, TRADES and MANUFACTURES; CHEMISTRY and CHEMICAL MANUFACTURES; AGRICULTURE, FARMING, GARDENING, AUCTIONEERING, LAND AGENCY, &c. Post Free on Application.

LONDON:
7, STATIONERS' HALL COURT, LUDGATE HILL, E.C.
AND
5, Broadway, Westminster, S.W.
1914